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THE MAIN TUNGSTEN AREA OF BOULDER COUNTY COLORADO

Reprinted with Additions from the

First Report of the Colorado Geological Survey

Boulder, Colorado
1916

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First Report of the Colorado Geological Survey

By

R. D. GEORGE

With Notes on the Intrusive Rocks by

R. D. CRAWFORD

Boulder, Colorado

1916

Department of Geology

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Page 23, line 33;

Page 62, line 36;

Page 74, last line. For Beddick read Beddig.

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INTRODUCTORY.

HISTORICAL.

Hubnerite, and probably wolframite have been known in the San Juan for over twenty years, and scheelite was long ago reported from Chaffee and Summit counties. A number of mines of the San Juan have produced a few tons of tungsten concentrates, mainly as a by-product, but no vigorous development of the hubnerite deposits has been attempted. In 1870 Sam P. Conger, the veteran prospector, discovered the Cariboo Mine and a few months later the Boulder County Mine. The Cariboo camp became very active, and both miners and prospectors soon became familiar with the heavy dark mineral which occurred as float in the district. It was called by various names, such as: "heavy iron," "hematite," "black iron," "barren silver," and others. Many assays were made, but its true character was not discovered until Conger's partner, W. H. Wanamaker, returned from Arizona, where he had seen the tungsten ore from the Dragoon Mountains. They kept the identity of the ferberite a secret, and started negotiations to secure possession by lease or otherwise of a part of the Boulder County ranch for the purpose of mining the placer tungsten ore and developing the veins. Conger secured the lease in August, 1900, and by the end of the year had taken out about 40 tons of high-grade ore. This was handled by the State Ore Sampling Company, Denver, and half of it netted about $1.60 per unit. The other half was sold to Mr. Morris Jones, representating the Great Western Exploration and Reduction Company, at $60.00 per ton, or $1.00 per unit. Mr. T. S. Waltemeyer was associated with Conger and Wanamaker, and concentrated their ore.

For 1901 a production of 65 tons, running 65 per cent. tungstic oxide, is reported. This was sold at about $2.25 per unit. In 1902 the market was extremely dull and much difficulty was experienced in selling the concentrates. But considerable prospecting was in progress and some development was done. The year 1903 was very favorable for the tungsten producer, and rapid development marked the history of the Boulder County area. From that time until nearly the end of 1907 development was reasonably steady. But the financial depression put a check upon

progress, from which the recovery is not even yet complete. Much exploratory and development work has been going on during the last few months, and the year 1909 promises considerable activity.

The field work was begun in the summer of 1907 and completed in the summer of 1908.

ACKNOWLEDGMENTS.

The writers take this opportunity of thanking all the owners, operators and managers of mines and mills for their assistance, which has contributed much to the value of this report. They would like to mention a few who were called upon more freely than were the others, and who were always ready to assist: Mr. C. F. Lake, Mr. Morris Jones, Mr. H. F. Watts, Mr. Wm. Loach, Mr. Henry E. Wood, Mr. V. G. Hills.

The greater part of the chemical work was done at the University of Colorado under the direction of Dr. J. B. Ekeley.

It would be impossible to acknowledge in the text of this report all the sources from which facts have been drawn. The literature of tungsten is extremely fragmentary and unsatisfactory, and many, perhaps the majority, of the references in the bibliography at the end of this report are to articles ranging in length from four or five lines to a page. Many more references could have been added, but the greater number would have been to matter outside the purpose of this report.

LOCATION.

The principal part of the tungsten district lies in the southeastern quarter of Boulder County, but some promising discoveries have been made in the northern part of Gilpin county. It is covered by the northern six miles of the Black Hawk, the southern two miles of the Boulder, and the northeastern corner of the Central City topographic maps of the U. S. Geological Survey. Another small area, not yet producing, lies chiefly east of Ward in the Boulder quadrangle. The principal places in the district are Nederland, Cardinal, Phoenixville, Rollinsville, Sugarloaf and Magnolia. The Denver, Boulder and Western, formerly The Colorado and Northwestern railway (operated by the Colorado and Southern) runs from Boulder into the tungsten field, and has stations at Sugarloaf, Tungsten and Cardinal. The Denver, Northwestern & Pacific, (The Moffat Road), has a

station at Rollinsville. A daily stage runs from Boulder to Nederland, eighteen miles.

TOPOGRAPHY.

The area is a part of a broad eastward-sloping upland belt extending from the ridges of upturned sedimentary rocks at the western border of the Great Plains, westward to the steeper slopes of the Front Range. This belt is an old erosion plain, now deeply dissected by a series of eastward flowing streams and their tributaries occupying canon-like valleys from which many gulches cut back well toward the divides. The principal streams of the area are North Boulder, Middle Boulder, South Boulder and Beaver Creeks. A few outstanding points such as Sugarloaf and Bald mountain, and those near Rollinsville, are erosion remnants of the earlier period of downcutting, which was approaching base level before the post-Laramie uplift, which increased the vigor of the streams and caused them to cut their deep narrow valleys in the resistant metamorphic rocks.

The transition from the western border of the plains to the eastern border of the upland belt is abrupt. Within a mile the difference of elevation may be as great as 2,000 feet, while the average elevation of the upland above the western border of the plains is about 2,500 feet. This greater elevation is due to two causes: *a.* differential uplift at the close of the Cretaceous, by which the foothills and mountain area was raised more than the plains region, and *b.* differential erosion—the more rapid lowering of the surface of the plains by the erosion of the less resistant sedimentary rocks of the plains.

CLIMATE AND VEGETATION.

The climate is that characteristic of the foothills. On the eastern border the annual rainfall (including snow) is about 16 inches, while that of the western border is somewhat greater. Vegetation is nowhere very abundant, though dense growths of evergreens cover many of the favorably situated slopes. The timber is seldom large.

CHAPTER I.—GENERAL GEOLOGY.

INTRODUCTION.

The area is wholly within the pre-Cambrian belt, called, in a broad way, the Front Range. The nearest sedimentary rocks, except recent stream and lake deposits, are three miles to the east. The most important rock is granite, generally more or less gneissoid. Next in importance is a granitic gneiss frequently grading into quartz-mica-schist and mica schist. While the areas occupied by these two units are, in a large way, well defined, there are numerous bodies of gneiss within the granite, and numerous bodies of granite within the gneiss. In a number of places there is no well-defined contact line between the two, but a band or zone in which the two rocks are mingled, and in which there is frequently a gradual transition from one type to the other.

Cutting the gneissoid granite and the gneiss are granite intrusions in the form of dikes and irregular bodies. In the western and northern parts are many dikes ranging in composition from acidic porphyries to latites, andesites, diabase and basalt.

The two main types of country rock mentioned above are themselves complex bodies, consisting, in each case, of a primary formation and many intruded rock masses. The ratio of the intruded rocks to the primary rocks varies from place to place, but for the whole region it is large. The intrusions vary in age, and consequently in the degree of change which they have undergone. The oldest, having passed through many of the metamorphic processes to which the containing formation has been subjected, bear a very close resemblance to it, and, in places, are with the greatest difficulty distinguished from it. The latest intrusions, on the other hand, probably date from the last great mountain-making disturbance, and consequently show comparatively slight metamorphism. Apart from the dike rocks, however, there is but little strictly non-metamorphic rock within the area. The beginnings of metamorphism are shown in the development of an indistinct directional structure, and in the partial assembling of the mica into

bunches and ill-defined planes. These alterations of the intruded rock are, as a rule, much more pronounced in the gneiss than in the granite.

THE GRANITE AND THE GNEISSOID GRANITE.

So far as the tungsten district is concerned, this is by far the most important rock, both in area occupied and in its relation to the ores.

Lithological character: Within the area mapped as granite there are very wide lithological variations. From the prevailing type—a slightly gneissoid granite—there are transitions, on the one hand, to a perfectly massive granite showing no evidence of directional structure or segregation of the minerals, and, on the other hand, to a rock in which the segregation of the mica, in particular, is very pronounced, and in which a directional structure is very noticeable. In certain parts of the area there seems to have been a poorly defined blocking of the rock in immense masses bounded by pronounced jointing zones or minor faultings. In the various mountain-making disturbances these masses acted as units somewhat as would the blocks of a pavement if it were thrown into undulations. As a result of these movements of adjustment along the zones of weakness, the rocks on both sides of the zone, on the outer borders of the masses, have been rendered gneissoid, or, in places, almost schistose. In other places the rock has been sheeted and sheared. The degree of change and the distance from the zone of movement to which the rock is affected would be roughly proportional to the magnitude of the force.

The mineral composition: The rock is an ordinary biotite granite, with occasional hornblende crystals. The feldspar is mainly orthoclase, and in the distinctly granitic part of the rock is the most important constituent. As the gneissoid character becomes prominent, the relative importance of the minerals changes, and quartz becomes increasingly important. A few granite masses, probably intrusions, show a porphyritic texture in which the feldspars reach from one-half inch to an inch in length. The quartz is in irregular grains and varies in amount, but in the massive granite makes up probably about twenty per cent. of the rock. The biotite of the fresh rock is in tabular crystals twice or three times as broad as thick, and forms perhaps eight per cent. of the rock.

Weathering: The rate of weathering depends quite largely upon the structure and texture of the rock. The more distinctly gneissoid forms weather most rapidly, and the massive granite least rapidly. This fact expresses itself in the topography. In many places the more massive granite forms rather prominent knobs and bosses, and a large percentage of the boulders of decay are granite. Occasionally, where the metamorphism has rendered the rock unusually rich in quartz, the gneiss is quite as resistant as the granite. In the weathering of the gneissoid forms, the mica segregated in bunches and minute lenses and irregular, discontinuous planes is the first mineral to yield. It forms a rusty green chloritic mineral which is very soft, inelastic and brittle. The weakening along these planes causes very rapid granular disintegration of the rock. This is still more marked in the sheeted and closely jointed rocks. The massive form shows a tendency to weather into rounded boulders, knobs and prominences by the slow and uniform penetration of the agencies of weathering. The coarse grained rock weathers more rapidly than the fine grained.

Origin: The intrusive character of a large part, possibly all of the granite and gneissoid granite, is evident from the field relations. Small bodies of hornblende-mica-schist and hornblende-schist of a dark-gray to almost black color, and rather low quartz content are quite numerous, and were evidently torn from an older formation through which the granite found its way to the surface. The contact with the gneiss is, in places characteristically an eruptive contact. Blocks of gneiss were caught up and surrounded by the granite, and arms and dike-like bodies of granite penetrate the gneiss, following and filling fissures formed at the time of the intrusion. In a few places traces of contact metamorphism are noticeable in the development of garnets and other minerals. In other places there are veinlets and stringers of very fine grained rock resulting from the rapid cooling of the molten granite in contact with the cold rock into which it was intruded.

GNEISS.

This rock is older than the granite, and, judging by the great degree of metamorphism it has undergone as compared with the granite, it is very much older. It lies mainly in the western and northwestern parts of the tungsten field. Within the gneiss area, rocks of all structures may be found, from massive granite to a perfectly laminated schist, but the prevailing type is the gneiss.

The typical rock has the general composition of a biotite granite, but the proportion of the different minerals varies widely, particularly across the strike of the structure. In places the rock can scarcely be distinguished from the granite, either in composition or structure, while in others the proportion of feldspar has greatly decreased, and that of the quartz has correspondingly increased. Other areas will show quartz and biotite, almost to the exclusion of feldspar. This rock frequently shows an advanced gneissoid, or even a schistose structure. While such transitions to the schist are by no means rare, the schist is usually in narrow bands which soon give way to the gneiss. Small areas of hornblende-gneiss-schist also occur. Attempts were made to map the schists, but it was found impossible to represent them satisfactorily on a map of the scale here used.

Structural features: In many places, as, for example, on the south side of Boulder Creek at Nederland, and on the north side of Beaver Creek, the dip and strike of the gneissoid structure are regular and well defined over considerable areas. But there is no general uniformity or agreement of dip and strike for the region as a whole. Areas which are apparently continuous show wide diversity of dip and strike. This discordance may be due to movements of rotation and tilting during mountain-making disturbances or at the time of the great granite intrusions of the eastern side of the field. West of the tungsten area toward the range there seems to be a greater regularity of dip and strike.

Origin: No absolute proof of the origin of the gneiss can be offered, but the following facts are in keeping with the view that it is derived from sediments. The broader bands of the gneiss differ widely in composition. One may be almost entirely mica and quartz while its contact neighbor may be a granite except for structure. Again, a granitic band may lie against one in which quartz may equal all other minerals together. Another band may show a considerable development of fibrolite while its contact neighbor may show none. These differences of mineral composition suggest such differences of original composition as may be found in successive strata of a sedimentary series. The regularity of the dip and strike of the gneissoid lamination suggests stratification. The fact that a few miles west on the slopes of Arapahoe Peaks there is a strong band of fine quartzite conforming in dip and strike to the structure of the gneiss in which it occurs, suggests a sedimentary origin for the containing rock which is lithologically and structurally similar to the gneiss of

the tungsten field. Again, about two miles to the east of the field on South Boulder and Coal Creeks, there is a great quartzite and schist series below the Paleozoic sediments, and in contact with the granite-gneiss series. The schists associated with the quartzite are so related to it that it is hardly possible to doubt their sedimentary origin. On both sides of the area we have metamorphic rocks derived from sediments. Between these lies the great granite and gneissoid-granite series which is in eruptive contact with the quartzite on the east and the gneiss containing the quartzite to the west. The general relations are consistent with the thought of a great metamorphic-sedimentary group intruded by a vast wedge of granite which has widely separated the two parts of the series. A great series of quartzites, quartz-mica schists and mica schists similar to that of Coal Creek is cut by the canyon of the Big Thompson River in Larimer County.

FINE-GRAINED GRANITE.

Within the granite area, a fine-grained biotite granite occurs in numerous masses, of which the largest exposure is shown on the map, about a mile northeast of Nederland. The same rock occurs near by in masses often but a few feet across, and in considerable amount between Magnolia and South Boulder Creek.

The rock is distinctly gneissoid, and where it occurs on the border of the ancient gneiss there is generally no well-defined contact between the two, owing to the fact that they have undergone a high degree of metamorphism which has developed pronounced directional structure in both. Specimens taken from mines usually show the mica to be leached out and the feldspar more or less kaolinized. In this state the rock might at first glance be taken for aplite. The fine-grained variety is cut by pegmatite dikes usually narrower than those cutting the coarser granite. This rock will be further described in connection with the ore bodies.

PEGMATITE.

Pegmatite, both coarse and fine, is very abundant throughout the tungsten field. The relations of the dikes (and veins) to the country rock indicate two modes of origin. There are some dikes which have been formed in much the same manner as dikes are generally formed—by the filling of fissures with molten or, at least, highly plastic rock. Whether the mass was in a state of aqueo-igneous fusion (or in mineral solution), water playing an important role, is not easily determined. Certain it is that in places the mass had sufficient density to pluck off and hold

suspended large blocks of the country rock, and that the country rock itself was solid enough to break with sharp angular outlines and retain its form even when surrounded by the pegmatite mass. That some of these dikes are contemporaneous with the solidification of the containing rocks seems very improbable. Erosion has removed a very considerable thickness from the surface of the country, and the parts of the dikes now exposed must have been formed at no small depth. But these plucked-off masses of country rock are found in the deeper workings of the mines. At the same time there is rarely any evidence of contact metamorphism between the blocks and the containing pegmatite or the country rock and the pegmatite. Occasionally the pegmatite dikes are bordered by a few inches of country rock containing little or no dark mineral, and consequently of lighter color than that a little further from the contact. This difference in composition is probably due to subsequent solution and replacement rather than to contact metamorphism. Textural variation from the wall toward the center of the dikes is noticeable. The dikes have well-defined walls and generally regular courses.

There are other veins, or irregular bodies, of pegmatite, mostly of finer texture, but still noticeably coarser than the containing rock, which have had an entirely different origin. They are the result of a process of solution and recrystallization of the country rock along seams and fracture lines. These bodies never have well-defined boundaries, but show a gradual transition to the texture and mineral composition of the country rock. The pegmatization frequently follows branching and rebranching fractures and penetrates the country rock irregularly on the two sides of the fractures, not infrequently resulting in the alteration of two-thirds of the rock volume. This type of pegmatite is particularly common in association with the ore bodies, and does not appear to be abundant elsewhere, although it may be found in parts of the field away from known ore bodies.

The coarse and fine pegmatites occurring in dike form are younger than the containing rocks, and though they do not belong to the latest period of movement and igneous activity, have suffered but little crushing. Three distinct periods of faulting have left their records in many of the dikes with which the ores are associated. The movements do not appear to have been great. In some instances the faulting and its accompanying phenomena follow one wall of the dike, while in others movement has occurred

on both sides, and in a few the crushing and movement have involved the whole dike. Rarely do the crushing and brecciation extend far into the country rock. Occasionally, however, the fault breccia contains much country rock. Both tension and compression movements have occurred, and the brecciation is probably more largely due to the latter than to the former.

The topographic effect of the pegmatite bodies is readily observable in both gneiss and granite, where it frequently forms ridges or knobs on account of its greater resistance to weathering. Occasionally, however, the course of a pegmatite body may be known only by the debris on the surface. While the greater part of this type of pegmatite occurs in dikes, irregular, lenticular, and plug-like bodies are quite common. These forms do not show such definite boundaries as do the dikes.

Mineral composition: In the order of their importance, the minerals of the regular pegmatite bodies are: Microcline, orthoclase, (possibly albite), quartz, biotite and muscovite. In some dikes and parts of dikes the feldspar may form almost the entire mass, while in other places quartz is the dominant mineral. Black mica is rarely important—seldom reaching one per cent. of the volume of the rock. Muscovite is remarkably irregular in its general distribution. In certain small sections of a few dikes it may form from five to ten per cent. of the rock and be uniformly distributed. In other cases it is more or less segregated near the walls of the dikes. In two pegmatite dikes to the north of the tungsten area muscovite is locally developed and segregated to such an extent that two or more mica prospects have been located on them. In many dikes quartz is much more abundant in the middle one-third than in the outer parts. A few show distinct banding, though it is rarely so well defined as that often found in vein structure.

The central band is generally quartz, and masses ranging from two or three to twenty-five feet in diameter are found. In these cases the dike locally resembles a strong quartz vein. Graphic granite occurs sparingly.

Small acid granite veins, ranging in width from a fraction of an inch to a few inches, are common in both the gneissoid granite and the gneiss. They are composed of feldspar and quartz with occasionally a meager sprinkling of biotite, and less commonly muscovite. Their composition and their relation to the containing rocks indicate an origin similar to that of the pegmatites.

Rare minerals and minerals in whose formation heated vapors and gases play an important part are characteristic of many pegmatite occurrences. But they are notably absent from the Boulder pegmatites. Ores of tin, antimony, molybdenum and tungsten are also looked for in pegmatites. But in this region, with the possible exception of a very occasional tourmaline crystal, and the doubtful occurrence of fluorite, the tungsten ores occur alone.

INTRUSIVE ROCKS.

By R. D. Crawford.

The intrusive rocks are almost entirely confined to intermediate and basic types. Excepting the pegmatite and aplite, rock of high acidity is found in only one dike, probably in small quantity, and as a differentiation product. Andesites predominate, but their near relatives, the latites and dacites, on the one hand, and basic rocks on the other, are well represented. The dikes are generally narrow; perhaps the majority are less than 20 feet wide, and a few less than 3 feet. They can usually be followed by their outcrops without difficulty, but are often greatly weathered.

The general trend of the dikes in the productive tungsten area is east and west. In the vicinity of the old Boulder County Mine and southward they are most numerous, but many of these are narrow and pinch out a short distance west of the boundary of the map. From Bald Mountain northward the dikes widen greatly, and trend nearly north and south.

Field relations furnish but little evidence of the relative age of the different dikes. Since the diabase is cut by a latite dike, perhaps an offset of the Sugarloaf dike, it is older than the latter rock. The limburgite appears to cut the diabase, but the exposure at the intersection of the two dikes is not very distinct. All the intrusive dikes are younger than the pegmatite. No other field observations made help to determine the succession. A light gray kaolinized dike rock, probably the felsite described below, occurs in the Beddick Mine, but does not reach the surface. The dike cuts the granite, but was intruded prior to the deposition of the ore.

In addition to the dike rocks described below, boulders of monzonite occur on the steep slopes of Eldora Mountain near the west border of the area. These blocks may not be far from their original position, but it is possible that they have fallen from the moraines above.

Andesites.

Hornblende andesite: In the dikes with a general east-west trend in the vicinity of Nederland, and as far east as Bald Mountain, the andesite is fairly uniform in texture and mineral composition. It is commonly medium to light gray, usually with a greenish tinge. It is seldom found quite fresh or dark in color. Although the phenocrysts are generally small, the rock is invariably porphyritic, with the larger crystals not infrequently about equal in amount to the ground-mass. Feldspar phenocrysts are greatly in excess of hornblende phenocrysts, and are commonly 1 to 3 mm. in diameter, though an occasional crystal may reach 5 or 6 mm. Ordinarily the hornblendes are less than 1 mm. in thickness, with a length of 2 to 4 mm.

Thin sections show that the phenocrystic feldspars are mainly andesine, but labradorite may sometimes be present. The hornblende is the common green variety with strong pleochroism. The felty groundmass is composed largely of poorly individualized feldspar laths, with interstitial feldspar and grains of magnetite. A few flakes of biotite are present in occasional specimens. These minerals, together with minute crystals of apatite enclosed in the phenocrysts and groundmass, are the only primary constituents now determinable. Kaolin, calcite, chlorite, epidote, quartz and iron oxides are present in variable amounts as alteration products.

The hornblende andesite dikes with a northward trend, in the vicinity of Bald and Sugarloaf mountains, differ from those described chiefly in color and in the quantity of biotite. These andesites range from very dark to very light grey, but the greenish cast so common in the dikes described above is usually lacking. Hornblende is here, also, the principal ferromagnesian constituent, but biotite very frequently is present in crystals often rounded by re-solution. Phenocrystic orthoclase appears in small amount.

Glassy hornblende andesite: This is a dense black rock, basaltic in appearance, with numerous hornblende phenocrysts and less numerous feldspars. Weathering makes the phenocrysts conspicuous, and brings out the fluxional arrangement of the hornblendes, which are commonly under 6 or 7 mm. in length.

Under the microscope the feldspar phenocrysts prove to be largely labradorite. The hornblende is brownish-green, and resembles the basaltic type. It occurs also in microscopic crystals in the ground mass with a few minute octahedrons of magnetite.

The ground mass varies in different specimens from glassy to microcrystalline. In the latter there are multitudes of lath-shaped feldspar microlites and grains of magnetite in a glassy base. Minute apatite crystals are present in both the glassy and microcrystalline varieties.

Mica andesite: This variety is dark brownish-gray, with texture very similar to the holocrystalline hornblende andesites, but biotite, instead of an accessory, is the most abundant ferromagnesian constituent. It occurs in shiny flakes, commonly under 1 mm. in diamenter. Prismatic crystals of what appears to have been hornblende are now completely replaced by secondary minerals—calcite, kaolin and iron ores. Under the microscope the felty groundmass does not differ materially from the others described. The feldspar phenocrysts are nearly all plagioclase, but the rock is a close relative of the latite of Sugarloaf Mountain. In the short dike west of Farewell Gulch augite occurs in considerable amount.

Pyroxene andesite: There are two distinct varieties of rock designated on the map as pyroxene andesite: (1) That of the dike crossing the railroad on the south slope of Bald Mountain; (2) that of the dikes in the vicinity of Beaver Creek.

The Bald Mountain type is rather dark grey, and carries a few small pyroxenes and fewer feldspar phenocrysts in a felsitic groundmass. But few phenocrysts of either mineral have a length of 2 mm. Under the microscope multitudes of lath-shaped feldspar with fluxional arrangement are seen. Though not many are 5 mm. long, they are almost all twinned after the albite or the Carlsbad law, or both. Extinction angles (with a maximum of 30°) indicate andesine-labradorite. The few phenocrysts may be somewhat more acid, but all are plagioclase. The pyroxene phenocrysts, and many smaller crystals and formless grains, are colorless augite, but the large proportion of small idiomorphic crystals of pyroxene with parallel extinction suggests the presence of an orthorhombic variety. Many small magnetite crystals and a few apatites are present. Nearly or quite all the interestitial base is anisotropic and apparently largely feldspar.

In the freshest exposures of the dikes in the vicinity of Beaver Creek, provisionally called pyroxene andesite, the surfaces of joint blocks are generally reddish, but the interior is greenish-gray. The most striking feature is the great abundance of feldspar phenocrysts with about one-twentieth as many phenocrysts of augite. Phenocrysts of these two minerals compose

approximately half the rock. The feldspars are commonly 2 to 4 mm. in diameter, bluish-gray in color, and usually without megascopic striae. The augite crystals are 1 to 4 mm. in thickness.

In thin section the feldspar phenocrysts are seen to be plagioclase, in large part labradorite, but apparently ranging from andesine to bytownite. The augite is pale green to coloress, and is frequently chloritized. Olivine occurs as an accessory in small but well-formed crystals, usually serpentinized. Serpentine is also scattered throughout the groundmass in considerable amount. Stout apatite crystals are not rare. Magnetite crystals are fairly common. The microcrystalline groundmass is composed almost entirely of feldspar in lath forms and irregular grains. The microlites are often once twinned, and many are doubtless plagioclase. In some specimens they appear to have undergone recrystallization.

Feldspar probably composes 80 per cent. to 90 per cent. of the rock which is apparently the aphanitic equivalent of anorthosite. It may be considered a transition form closely related to the basalts. When material is found sufficiently fresh to warrant minute study, a more detailed description will be given.

Felsite.

The felsite is bluish-gray in the least weathered exposures, but ordinarily it is almost white through kaolinization. Black or greenish prismatic phenocrysts of hornlende or its alteration products can be seen in the less weathered varieties, becoming very noticeable when the surface of the rock is wet. A few phenocrysts of feldspar 1 or 2 mm. in diameter can be seen in the fresher specimens, but are completely replaced by kaolin in the more altered rock.

In thin section some of the feldspars retain traces of polysynthetic twinning, but more frequently a trace of Carlsbad twinning. Whether or not all were plagioclase it is impossible to say. The hornblende has lost almost completely its primary character. The groundmass is composed largely of irregular grains and lath-shaped feldspar microlites, with considerable hornblende and secondary material. The microlites of feldspar are often once twinned. The rock is probably andesite, but since it is distinctly different in textural character from the other andesites in the district, and since there is much uncertainty as to the mineral composition, it seems best to retain the field term "felsite."

Dacite.

The dacite, or quartz andesite, is very similar in color and texture to the hornblende andesites in the vicinity of Nederland. Phenocrysts of feldspar and biotite make up about half the rock. The biotite is abundant in shiny flakes usually about 1 mm. in diameter, or less. The unaided eye can detect an occasional hornblende crystal. A few quartz phenocrysts 1 to 2 mm. in diameter can be seen. They are more evident in the weathered rock, which is otherwise similar to the weathered andesite.

In thin sections quartz phenocrysts are numerous, invariably in rounded forms resulting from re-solution. The biotite often shows the characteristic hexagonal outline. The feldspar phenocrysts are plagioclase. What has been said above in regard to the accessory and secondary minerals and felty groundmass of the holocrystalline hornblende andesite applies to this rock practically without modification.

The very short dike near the road, about a quarter of a mile southeast of the old Boulder County mine, apparently carries much more hornblende than the other dacite dikes. It is badly altered and no microscopic determinations were made.

Latite.

Latite occurs in far greater amount not far north of this region. The strongest dike in the area mapped passes through Sugarloaf Mountain, where it reaches a width of perhaps 60 feet or more, and has been in large measure responsible for the development of the peak. The rock from this dike was once described as andesite,[1] but inasmuch as it contains a large amount of orthoclase and passes into a trachyte toward the northeast, it seems best to consider it latite throughout the entire length of the dike. The chemical analysis[2] indicates its trachytic character, or position intermediate between andesite and trachyte.

The rock contains numerous phenocrysts of feldspar and biotite, less abundant pyroxene and hornblende, and a few crystals of titanite. Feldspar, in white, sometimes glassy crystals usually less than 2 mm. in diameter, is by far the most important phenocrystic mineral. Biotite flakes are commonly less

1Hogarty, Barry, Proceedings of the Colorado Scientific Society, Vol. VI., pp. 173-185.
2Ibid., p. 181.

than 1 mm. in diameter. The hornblende and pyroxene prisms are usually not more than 3 mm. long.

The microscope shows the ratio of plagioclase to orthoclase to be about 2 to 1, and the plagioclase to be largely andesine. The biotite is often in perfect crystals, generally with a border suggesting re-solution.

Pyroxene ranks next to biotite in amount. It is pale green, weakly pleochroic, and has the extinction angle of augite. The hornblende is the common green variety with strong pleochroism. Almost invariably the crystals show a re-solution border. Titanite appears as a constant accessory in idiomorphic crystals. The felty groundmass is composed of poorly individualized feldspar microlites with interstitial quartz and possibly feldspar, besides numerous grains of magnetite and much secondary calcite. The quartz is probably chiefly secondary. The feldspar microlites are often once twinned, and have parallel extinction. Practically all of the original constituents show much alteration.

The dike, about a mile east of Rollinsville, is provisionally mapped as latite until fresher material than that at present available for examination may be found. In the freshest exposures observed the rock is greenish or reddish, with feldspar phenocrysts in only moderate numbers, and fewer augite crystals. Under the microscope magnetite, chlorite and calcite appear in the groundmass, which seems to be composed largely of recrystallized or secondary feldspar. The phenocrysts are badly altered, but a few appear to be orthoclase.

Latite Porphyry.

The long east-west dike passing through the high points north of Beaver and South Boulder creeks and Winiger Gulch is of interest chiefly because of the variety that it presents. It can usually be traced only by means of surface boulders. Not one good exposure occurs, and the few shallow prospect holes do not uncover the full width of the dike. Although distinct gradations probably exist, there is no opportunity to observe them in the field, and hence for purposes of description it seems best to consider the characteristic varieties separately. Along the line of the dike, boulders of two or three varieties are usually found, and their disposition gives no clue to the arrangement of the different kinds of rock in

place, but it is possible that several instrusions have followed the same line of weakness.

The variety which perhaps occurs in greatest abundance, ranges from a rock composed almost entirely of feldspar phenocrysts 1 to 2 mm. in diameter, with practically no groundmass, to a phase in which part of the phenocrysts reach 8 or 10 mm. in diameter, while the groundmass makes up about two-thirds of the rock. The freshest specimens are bluish-gray in color, and, in addition to the lustrous feldspars, contain many small patches of kaolin and iron oxides replacing hornblende. More weathered specimens are pinkish white and white, containing numerous fresh feldspars, and show many small cavities from which some mineral has been dissolved.

Under the microscope the feldspars are seen to be both orthoclase and acid plagioclase, with the latter in excess in part of the rock, and again almost disappearing from some specimens with much groundmass, when the rock becomes a typical trachyte. In the phase which is nearly devoid of groundmass, the two kinds of feldspar show examples of perthitic intergrowth, and a number of the orthoclases enclose plagioclase in poikilitic manner. In some sections small crystals of biotite are present and the same mineral, in aggregates of minute flakes, occasionally replaces some primary constituent. The groundmass is composed largely of small grains of unstriated feldspar and a little quartz, the latter in large part secondary.

Another phase contains phenocrysts of sanidine up to 15 mm. in diameter, with a multitude of smaller feldspar crystals, the majority of which are plagioclase. Zircon and apatite are present as inclusions. Hornblende and its alteration products occur as in the variety described above.

A quartz-bearing latite porphyry may be considered to represent a transition toward the rhyolite porphyry described below. It contains feldspars of three periods of crystallization. Of the first period there are comparatively few orthoclase phenocrysts with a maximum length of 2 cm. In the second generation both orthoclase and plagioclase occur in rectangular forms 1 or 2 mm. across, with plagioclase in excess. The groundmass contains the feldspars of the third period, which in thin section are seen to be formless grains of orthoclase. The naked eye can also detect many small flakes of biotite which

are microscopically seen to be both primary and secondary. Quartz occurs in small phenocrysts corroded by the groundmass, of which it contains numerous inclusions.

Boulders of soda-rhyolite-porphyry can be found almost the entire length of the dike, often in great abundance. Numerous phenocrysts of quartz, feldspar and biotite occur in a granular groundmass. The largest feldspar phenocrysts, which are practically all orthoclase, stand out conspicuously on weathered surfaces. They are from 1 to 2.5 cm. long, and make up one-fourth to one-half the rock. Quartz phenocrysts reach a diameter of 7 or 8 mm., but are usually smaller. They are commonly rounded and very irregularly distributed, varying from almost none to 15 per square inch of surface. This inconstancy in distribution in a rock with both orthoclase and plagioclase is the best evidence we have that the rhyolite and quartz free latite are phases of a single intrusion. Biotite is not seen in all specimens, but may be quite abundant locally in flakes 2 mm. or less in diameter.

The microscope shows orthoclase and plagioclase phenocrysts of medium size. Crystal outlines are generally distinct, but the crystals have suffered grinding and crushing at the margin and are sometimes broken in two. The quartz phenocrysts show no crystal outline, and have been subjected to similar grinding. Zircon and apatite are enclosed by the quartz and feldspars. The groundmass is a holocrystalline aggregate of quartz, orthoclase and plagioclase.

The short dike of latite porphyry in Farewell Gulch contains sanidine phenocrysts up to 2 cm. across, together with many smaller crystals of both orthoclase and plagioclase in a much altered groundmass.

Diabase.

This rock occurs in only two dikes within the area mapped, the longer one of which has been traced approximately ten miles and has a maximum width of about 70 feet. The diabase is dark greenish-grey, very heavy and extremely tough. Greenish-gray lath-shaped feldspars, black pyroxene and magnetite or ilmenite are the essential constituents, with pyrite as an occasional accessory. The feldspar laths are rarely over 3 or 4 mm. long. Pyroxene and the iron ores are almost entirely with-

out crystal boundaries, but are packed in the interstices among the feldspars, producing true diabasic texture. This is best shown on weathered surfaces.

In thin section the feldspar is seen to be almost entirely andesine-labradorite with the usual albite twinning sometimes combined with Carlsbad twinning. The pyroxene is in part augite with a somewhat less amount of hypersthene. The augite is pale brown, and often uralitized and chloritized. The hypersthene is pale yellow, contains the characteristic inclusions, and is frequently serpentinized. Black iron ore, highly titaniferous, is abundant. Apatite is a common accessory enclosed by the other minerals. Very rarely the rock is found in an approximately unweathered state.

Lamprophyre.

The few exposures of lamprophyre that occur might easily be passed over in the field unobserved because of their resemblance in color to the weathered gneiss. Freshest specimens are greenish-gray and show small grains of feldspar less than 1 mm. in diameter and a great amount of epidote.

The microscope shows the rock to be a holocrystalline aggregate of feldspar, epidote, hornblende and magnetite, with apatite crystals enclosed by the essential constituents. Feldspar makes up nearly half of the rock, both orthoclase and plagioclase being present. The extinction angles of the plagioclase indicate albite. Some of the feldspars approach idiomorphic forms, but more are entirely without crystal outline. Many crystals are partly replaced by epidote, the replacement beginning usually at the center of the crystal. Small prismatic, acicular crystals of amphibole seem to have crystallized earlier than the feldspars. A trace of the orthopinacoidal twinning can still be seen, though the mineral is in great degree epidotized. Epidote occurs in an amount equal to that of the feldspar, replacing crystals of amphibole and in irregular masses in and between the feldspars. Other secondary minerals in small quantities are chlorite, serpentine and quartz. The magnetite is perhaps both primary and secondary.

Basalt and Basalt Porphyries.

Basalt: As a rule the basalts are decidedly porphyritic, but a few dikes occur which cannot properly be called basalt porphyry. In the less porphyritic form, the rock is very compact, with numerous cavities on weathered surfaces which doubtless

mark the former position of ferro-magnesian minerals. On freshly broken surfaces, these do not appear, but many small patches of limonite attest the presence of pyroxene in the original rock.

Idiomorphic augite crystals with a maximum thickness of .5 mm. are seen under the microscope, but these are badly altered. Numerous prismatic forms with the extinction angle of hornblende occur, but they are too badly weathered to permit certain identification. Magnetite is abundant. Serpentine apparently replaces small olivine crystals and occurs throughout the slide in company with chlorite. Minute lath-shaped feldspars compose less than half the rock. Interstitial augite occurs in irregular grains, and minute crystals of apatite are abundant.

In a short dike north of Sherwood Creek a porphyritic basalt occurs, in which the feldspar phenocrysts far outnumber the augites. This rock is more nearly related to the andesites than are the other basalts.

Hornblende basalts: Two varieties of hornblende basalt are present: (1), without olivine and augite; (2), with olivine and augite. The first occurs in a narrow dike a quarter of a mile south of the old Boulder County Mine. It is dark gray with very few phenocrysts of feldspar and numerous phenocrysts of what appears to be hornblende.

The microscope shows that the hornblende has undergone complete recrystallization. The mineral is replaced by aggregates of minute biotite flakes with considerable calcite, magnetite and a small amount of quartz. Inclusions of apatite are present. The biotite is brownish-green with strong pleochroism and high interference colors. The feldspar phenocrysts are too badly altered to be identified. The groundmass is composed of striated and unstriated feldspar, small flakes of biotite, grains of magnetite and crystals of apatite, with secondary quartz and calcite.

The second variety of hornblende basalt is found in a narrow dike south of Nederland, crossing the old Rollinsville road. This rock contains a multitude of hornblende phenocrysts with a few augites which can be determined in the hand specimen. Most of the phenocrysts are not over 6 or 7 mm. long, but a few reach twice that length.

The hornblende is brownish-green in thin section and extinguishes at about 15°. Zonal banding is very marked. The augite is almost coloress and non-pleochroic. The crystals have apparently suffered some re-solution and are bordered, in a few cases, by grains of augite, variously oriented. A few small crys-

tals of olivine are present, but are mostly replaced by serpentine. The groundmass is composed of microlites of feldspar and augite with small grains of magnetite.

Basalt porphyry: This occurs in several dikes, but the freshest rock is exposed at the railway east of Rollinsville, where the dike is 7 or 8 feet wide. The rock contains abundant phenocrysts of augite and feldspar in a dense, microcrystalline, dark gray groundmass. The augites are usually less than 5 mm. long, but a few reach a length of 1 cm. The feldspars are usually less than 2 mm. in diameter and are bluish-gray with a vitreous luster in the least altered rock. They become white and more conspicuous through kaolinization. The groundmass becomes greenish or light gray through weathering, or on sheltered surfaces often has a reddish cast.

Under the microscope the rock is seen to be holocrystalline, with the phenocrysts composing one-fourth to one-third of the rock. The augite is pale green and slightly pleochroic. Olivine occurs in idiomorphic crystals 1 mm. long, or less. These phenocrysts are less numerous than the augites. Alteration to serpentine is common, some crystals being completely replaced. The feldspars are largely basic labradorite or bytownite, and probably exceed the augites in number. The groundmass is composed of minute feldspar laths, and interstitial magnetite, pyroxene and olivine. Apatite needles are abundant as inclusions.

A much coarser textured rock occurs in the dike about a quarter of a mile south of Cardinal Station. In this rock a few feldspars reach a diameter of 1 cm., but are mostly under 3 mm. The pyroxene phenocrysts are more numerous. Small crystals of pyrite are occasionally present. The naked eye can distinguish the feldspar grains and magnetite of the groundmass. In addition to these minerals, the microscope shows an abundance of minute apatite crystals and flakes of chloritized biotite in the groundmass, besides many olivine crystals of small size. The augite is invariably uralitized.

Pyroxenite.

This is a greenish-gray, even-grained rock, composed almost entirely of pyroxene. The texture varies, but is always sufficiently coarse to show the cleavage surfaces, which sometimes have a sub-metallic luster. The microscope shows the presence of both monoclinic and orthorhombic pyroxene, and perhaps an amphi-

bole, but the material collected is too unsatisfactory for further description.

Limburgite.

The several exposures of this rock are probably all in one dike, which is so narrow that it does not reach the surface continuously along its course. The width ranges from less than a foot to about four feet. The rock is almost black, and basaltic in appearance. It contains abundant grains and pseudomorphs of serpentine from less than 1 mm. in diameter to 3 or 4 mm. Brown mica, in occasional small crystals, is the only primary megascopic constituent. Amygdaloids of calcite are common. They are usually less than 1 cm. in diameter. Fragments of the country rock usually rounded by corrosion are very commonly enclosed by the dike. These inclusions are generally less than 2 inches in diameter.

The microscope shows abundant olivine, which, in its phenocrystic form rarely reaches a diameter of 5 or 6 mm. Much of the olive is serpentinized, and green chlorite occasionally accompanies the serpentine. Olivine in smaller crystals and grains, minute prismatic crystals and grains of augite, grains of magnetite and multitudes of apatite microlites make up nearly the entire rock mass. These occur in a colorless, isotropic base which is very subordinate in amount.

SURFACE DEPOSITS.

Glacial: The town of Nederland is just within the glaciated area. Glaciers coming down from the crest of the range, in their greatest extension down Middle Boulder Creek, passed but a short distance beyond Nederland. The source of all the morainal deposits of the region is to the westward, northwestward, and perhaps a little to the southwestward. It is not unlikely that the main ice streams of South Boulder, Middle Boulder and North Boulder Canyons may have coalesced on the lower portions of the divide, as morainal matter is found at high points adjacent to the canyons. Little is yet known as to distinct periods of extension and retreat of the glaciers of the region, but whatever fluctuations there may have been, the general movement of the ice was probably always from west to east, though varying a few degrees locally. Hence it is safe to say that all the ma-

terial of the various moraines has in a general way come from a westerly direction. The drift is without doubt chiefly Pleistocene, but inasmuch as moraines are now forming at the foot of Arapahoe Glacier, those in the west part of the area under consideration should perhaps be considered in part Recent.

The drift material is a mixture of glacial clay and boulders, which include gneiss, granite and porphyries, some of which are not represented in the unglaciated area toward the east. The boulders range in size from mere pebbles to masses several feet in diameter. Angular forms are sometimes present, but the boulders are commonly more or less rounded as the result of a rolling, grinding movement. Such faceting as occurs is usually obscure, and the character of the material leads to rapid weathering, so that any polishing and striation that may have been originally present have been destroyed on all material examined.

Alluvial: In the western part of the area where streams have only a moderate gradient, North, Middle and South Boulder Creeks have locally accumulated a considerable depth of alluvium. Gold placers were formerly worked in South Boulder at Pactolus and near the mouth of Winiger Creek. In the meadows in Middle Boulder Creek, about two miles above Nederland, the alluvium is largely of lacustrine origin, doubtless deposited in a glacial lake which has since been drained by a lowering of the outlet. The alluvium of the Barker Meadows just east of Nederland was also deposited in a lake formed by the damming of the channel, probably by stream-carried glacial debris at the dam site of the Eastern Colorado Power Company.

Exposed rock surfaces gradually become covered by a thin layer of mineral grains and rock fragments of various sizes, which have been loosened from the parent mass in the ordinary processes of weathering. By further decay of this detritus a matrix of clay and fine rock grains fills the spaces between the fragments. Heavy showers, forming temporary streams and sheets of water, sweep this material from the steep mountain and hill sides to the gentler slopes of the valley, where the stream loses its force, spreads over the surface or sinks into the ground, and its load of detritus is left stranded. Such deposits of sheet-wash or slope-wash are formed most rapidly where small, steep ravines join the larger valley with its gentler slopes. If these

small ravines or notches are numerous, these deposits may spread until their edges unite and the gentler slopes of the larger valley may be deeply buried by a continuous sheet. Such sheets of slope-wash occur locally along all the main streams of the tungsten area. The more prominent examples of this kind are on the north side of Beaver Creek, near Pactolus on South Boulder, and east and west of Nederland on Middle Boulder.

CHAPTER II.—ECONOMIC GEOLOGY.

TUNGSTEN MINERALS.

The tungsten of commerce is obtained almost exclusively from the four minerals: wolframite, ferberite, hubnerite and scheelite.

Hubnerite is theoretically a tungstate of manganese, Mn WO_4, but iron generally replaces a small part of the manganese. The average of eleven analyses of hubnerite gives the following percentage composition:

WO_3 (tungstic oxide)	75.23
FeO (ferrous oxide)	2.11
MnO (manganous oxide)	23.07

Well-formed crystals of hubnerite are very rare, but forms with two or three crystal faces are somewhat common. The mineral shows a tendency to form groups of bladed, prismatic, and needle-like crystals in which the individuals are frequently divergent. Thin tabular forms occur alone, and in lamellar masses. Compact, granular ore is common. The cleavage is perfect. The color of the crystal faces is usually dark brown to black; but the flat, very smooth or splintery cleavage faces are commonly reddish brown to hair-brown, and sometimes black. It is easily scratched with a knife, and the powder formed shows lighter shades of brown than the surface from which it comes. (The water-made concentrates from some of the San Juan ores of Colorado are very dark—almost bluish black.) The luster of crystal surfaces is bright submetallic, while that of cleavage and fracture surfaces is submetallic to resinous. The specific gravity is 7.2 to 7.5, or about three times that of quartz or granite. The fusibility depends upon the purity. Thin splinters of the pure mineral are readily fused before the blowpipe, and small grains will fuse rather readily in the forge. If quartz is intimately mingled with the mineral, as is frequently the case, it becomes difficultly fusible, and sometimes almost infusible before the blowpipe.

Wolframite is an iron-manganese tungstate in which the ratio of iron to manganese may range from 9:1 to 2:3. This varia-

tion in the ratio of two of the three metallic elements results in a varying percentage of each of the metallic oxides composing the mineral. With the increase of the iron percentage, it approaches ferberite, and with the increase of manganese it becomes more like hubnerite. The average of about 20 analyses gives the following result:

WO_3 (tungstic oxide)	76.0%
FeO (ferrous oxide)	16.0%
MnO (manganous oxide)	7.7%

With some modifications, the description of hubnerite would apply to wolframite. The color is dark brown to black, and sometimes dark steel gray. The powder and streak are generally dark-brownish black, but may be black or grayish black. The luster of cleavage surfaces is fairly bright submetallic. The cleavage of crystals is good and causes them to break into plates. As an ore it is commonly massive granular, but druses or crusts of ore frequently show enough crystal faces to make out prismatic and chisel-shaped forms. The granular aggregates are likely to part between the crystal grains and show comparatively few cleavage faces, while the broken or bruised surfaces of druses will show many cleavage planes which may be mistaken for crystal faces.

Scheelite is a calcium tungstate, $CaWO_4$, with WO_3 80.6% and CaO 19.4%. Molybdenum may replace part of the tungsten. In color it varies from colorless and transparent to honey-yellow, greenish yellow, to rusty brown, pink and reddish. Crystals are frequently found on the walls of cavities. Four-sided pyramids and octahedral forms are commonest. Tabular forms and forms described under wolframite and ferberite are found—the latter are pseudomorphs after wolframite or ferberite. The luster of crystal faces is vitreous to adamantine, while that of fractures and cleavage faces is less brilliant, and inclines, at times, to resinous and greasy. The mineral is often coarsely granular, with cleavage faces fairly prominent on the broken surface of the mass. It is rather easily scratched with a knife, has a specific gravity of 6, or a little more than double that of quartz. It is readily soluble in nitric and hydrochloric (muriatic) acid, with the formation of a yellow powder, tungsten-trioxide, which is soluble in ammonia. (Pour off excess of acid, leaving yellow powder behind. Add ammonia liberally.) The yellow powder treated with zinc or tin in the acid solution is

reduced to a lower oxide form having a beautiful blue color, changing slowly through wine color and purple to brown.

Minerals which resemble scheelite are: quartz, barite (barium sulphate), witherite (barium carbonate), anglesite (lead sulphate), and cerussite (lead carbonate). The following table gives the distinguishing features of these minerals and scheelite:

	Hardness compared with knife blade.	Weight compared with equal volume of granite or quartz.	Cleavage—tendency to split with smooth flat faces.	Fusibility in forge or before blowpipe.	Solubility in hydrochloric and nitric acids.	Flame coloration.
Scheelite.....	Scratched by knife.	Over twice as heavy.	Fair in one direction.	Rather difficult.	Easily soluble in both—forming yellow powder.	None.
Quartz.....	Scratches steel.	About same.	None.	Infusible.	Insoluble.	None.
Barite.....	(2.5-3.5) Very easily scratched	Nearly twice.	Good in two directions.	Easily fusible.	Insoluble.	Yellowish green.
Witherite....	(3.-3.75) Easily scratched.	One and one-half times.	Fair in one direction.	Very easily.	Soluble in hydrochloric.	Yellowish green.
Anglesite.....	Very easily Scratched.	Same as scheelite.	Two fair; very brittle.	Very easily, boils and spurts and yields metallic lead.	Difficulty in nitric acid.	Not distinctive.
Cerussite.....	Very easily Scratched.	Slightly heavier than scheelite.	Two fair.	Very easily, and gives metallic lead.	Soluble in dilute nitric.	Not distinctive.

Ferberite: The name was first applied to an iron-manganese tungstate from the Sierra Almagrera, Spain, which contained 3.0 per cent. of MnO. The view that the name should be reserved for a practically pure ferrous tungstate seems to be somewhat prevalent, but the example above, and the common usage in regard to other minerals, do not justify this restriction. Dana does not mention any crystallographic difference between ferberite and wolframite greater than that recorded between different hubnerite crystals. Reinite (34, p. 991) is a pure ferrous tungstate from Japan, but the crystals are probably pseudomorphs after scheelite. A "wolframite" from the Black Hills (34 "Appendix," p. 73), is said to show no reaction for manganese, and is "inferred to be the pure iron tungstate." The crystal angles correspond closely with those of ordinary wolframite. In speaking of artificial ferrous tungstate, Dana says (34, p. 985): "A little manganese is also present." The following analyses of ores from the Nederland-Beaver Creek part of the field show a very small percentage of manganese, and when the parts not essential to the mineral are eliminated, the remainders show an excess of ferrous oxide over that required to make the ferrous tungstate, $FeWO_4$. Magnetite is present in small amount in most of the ores and in some of the gangue material, but the ferric iron was not worked out, and therefore the extent to which this excess of iron would be reduced by eliminating the magnetite cannot be determined. A few inexact tests of Nederland ores show from .5 to 1.2 per cent. of magnetite. Dana suggests that the ferberite molecule may be $n\ FeWO_4.FeO$. This would take care of the excess of FeO.

The manganous oxide, MnO, of the complete ore analyses averages 0.5 per cent., and that of the same analyses after the non-essentials are removed averages 0.56. (Similar results are shown by the partial analyses of ores and concentrates from the same part of the field.) If, as suggested by Roscoe and Schorlemmer (98, p. 1058), the MnO is taken with the FeO the composition would be $n\ FeWO_4.(FeMn)O$. In the Nederland-Beaver Creek ores the value of n would range from 3 to 21. Comparing these with Dana's analyses of ferberite, it is evident that they are much more nearly pure ferrous tungstates than was the original ferberite. Dana also says (34, p. 983), "Hubnerite is nearly pure $MnWO_4$." But the ten analyses given (34, p. 984) all contain FeO, and the average percentage is 2.11. These ferberites are

therefore more nearly pure ferrous tungstates than are Dana's hubnerites pure manganese tungstates.

Analyses of Ferberite from the Nederland-Beaver Creek area:

	WO_3	FeO	MnO	CaO	SiO_2	Al_2O_3	MgO
Clyde Mine	61.15	19.33	0.51	0.38	16.10	2.49	0.39
Barker Ranch	65.88	24.14	0.37	0.35	6.45	2.19	0.50
Conger Mine	60.98	19.13	0.08	0.44	15.94	3.10	0.59
Last Chance	62.30	19.90	0.69	0.79	14.68	1.34	---
Magnolia	73.94	23.85	0.67	0.60	0.49	0.25	0.12
Elsie	73.52	22.65	0.60	0.42	1.81	0.75	---
Manchester Lake	74.13	23.15	0.56	1.28	0.71	0.46	---

As scheelite is present in many of the mines, it is probable that most of the CaO comes from that mineral. A small part may come from the feldspar of the gangue, but as plagioclase is rather rare, in the rock fragments, the quantity of CaO from this source may be neglected. Assuming that the CaO is from the scheelite, and deducting enough tungstic oxide to satisfy it, and eliminating the silica, alumina and magnesia as non-essentials, the analyses in the first group, reduced to a basis of one hundred per cent., would read:

	WO_3	FeO	MnO	Excess of FeO
Clyde Mine	75.28	24.43	0.64	1.06
Barker Ranch	72.36	27.11	0.42	4.65
Conger Mine	75.68	24.47	0.10	0.99
Last Chance	73.92	24.92	0.86	1.99
Magnolia	74.58	24.90	0.70	1.75
Elsie	75.35	23.76	0.60	0.38
Manchester Lake	74.57	25.12	0.61	1.98

*Partial analyses of Nederland ores:

WO_3	MnO
39.82	0.53
35.12	0.38
41.52	0.52
50.20	0.56
20.52	0.30
21.00	0.31
64.90	0.93

*Assays by H. F. Watts, Boulder.

*Partial analyses of Nederland concentrates:

WO_3	MnO
60.42	0.64
52.30	0.38
61.10	0.69
62.49	0.50
63.21	0.64
61.50	0.66

Analyses of ores from the northeastern area: The following three analyses are of ores from the northeastern area. These, and assay returns from both ores and concentrates, show higher percentages of manganous oxide for this part of the field. A large number of assays and analyses made by the Colorado Tungsten Corporation at the Boyd Mill show an average of 3 per cent. manganous oxide, MnO.

	WO_3	FeO	MnO	CaO	SiO_2	Al_2O_3	MgO
Boulder Falls	70.42	19.85	3.36	2.87	2.37	1.26	---
Hal Harlow	55.05	17.69	1.47	3.05	19.23	3.70	---
Gordon Gulch	61.80	16.36	3.12	0.35	15.93	1.06	1.71

After satisfying the CaO with WO_3 (to form scheelite), and eliminating the silica, alumina and magnesia, the following results are obtained by reducing the remainders to the basis of 100 per cent.:

	WO_3	FeO	MnO
Boulder Falls	71.70	24.32	4.16
Hal Harlow	69.02	28.78	2.39
Gordon Gulch	75.85	20.56	3.92

By treating Dana's ferberite analyses (34, p. 985), in the same way, it is found that the ratio of MnO to WO_3 is practically the same as in these three. The average percentage of manganous oxide for the ten analyses above is 1.44, while the lowest percentage given in Dana's analyses of wolframite is 2.37 and the average is 7.66 (34, p. 984).

The following are analyses of tungsten minerals from other parts of the State:

Wolframite:

	WO_3	FeO	MnO	CaO	SiO_2	Al_2O_3
1Sultan Mountain, near Silverton	74.09	11.07	14.35	---	0.43	---
Johnnie Ward Mine, Ward.	71.27	20.01	7.15	1.58	---	---

*Assays by H. F. Watts, Boulder.
1 From Dana's System of Mineralogy, page 984.

Hubnerite:

	WO_3	FeO	MnO	CaO	SiO_2	Al_2O_3
Natalie Mine, Gladstone	70.21	2.03	21.72	0.37	4.91	0.56
[1]N. Star Mine, Silverton	74.75	2.91	21.93	0.11	---	---
[1]Cement Creek, Silverton	76.63	1.61	21.78	0.09	---	---
[1]Ouray County	75.58	0.24	23.40	0.13	---	---

The ferberite is generally almost black, with a slight tendency to brownish black, and on fresh granular surfaces a weak steel gray color. The luster varies with the surface examined. Natural crystal surfaces are usually submetallic to dull submetallic, while cleavage surfaces are brilliant submetallic, often rivaling black mica in brightness. The fresh surfaces of the massive, granular mineral frequently show a rather high submetallic luster. The cleavage is perfect, and the mineral shows a tendency to break into thin crumbling plates. Small crystals are common in cavities. The prevailing forms are thick, chisel-shaped, having two curved, and generally striated, faces, converging to form the cutting edge of the chisel. The other two faces are parallel, and approximately at right angles to the cutting edge. Lance or spear-head crystals are also rather common—the longer diameter of the cross section of the spear-head being double the shorter. Loose bunches of lath-shaped and slender prismatic crystals are found. These crystals commonly lie with their longer dimensions parallel to the surface to which they are attached. The great bulk of the ore is very fine, massive granular. The specific gravity ranges from 7.1 to 7.5 (nearly three times that of quartz). The streak made on a light colored, hard surface, or on rough porcelain, is dark grayish black, with a suggestion of brown. The powder made by scratching the surface with a knife is black to very dark brownish black.

The fusibility varies with the purity. The pure mineral, in thin splinters, is rounded and fused with no great difficulty, but the siliceous granular ore is nearly infusible. The fusibility seems to vary with the percentage of manganese present. Even pure crystal fragments of the ore almost free from manganese are difficultly fusible, and the siliceous ore of the same composition remains practically unchanged before the blowpipe.

Minerals resembling the dark tungsten ores: Minerals which may be mistaken for wolframite, ferberite and hubnerite are: magnetite and hematite (iron oxides); limonite, goethite and turgite (hydrous oxides of iron); ilmenite (iron-titanium oxide);

1 From Dana's System of Mineralogy, page 984.

psilomelane, manganite (hydrous oxides of manganese); pyrolusite (oxide of manganese); rutile (titanium oxide); cassiterite (tinstone, tin oxide); tourmaline (a complex silicate of boron, aluminum, etc.). All of these but manganite, ilmenite and tourmaline are infusible. Manganite and ilmenite are nearly infusible, and black tourmaline is very difficultly fusible. In specific gravity, all except cassiterite are far below the tungsten minerals. The heaviest, hematite and magnetite, are about twice as heavy, volume for volume, as granite, while tourmaline is only slightly heavier than granite. The tungsten minerals are nearly or quite three times as heavy as granite. The three tungsten minerals have very perfect cleavage. Only manganite, turgite (and rutile) resemble them in this respect. Manganite and pyrolusite are quite soft, while rutile, cassiterite and tourmaline are harder than the tungsten ores and can scarcely be scratched with a knife. The others have about the same hardness as the dark tungsten ores. All but rutile and tourmaline are soluble in hydrochloric acid (cassiterite nearly insoluble), but only ilmenite gives a yellow solution. The yellow color of the tungsten solution is due to the formation of yellow tungstic oxide, which soon settles to the bottom after boiling ceases, while that of the ilmenite solution is a true coloration. The tungsten minerals are much more brittle and easily powdered than are the iron ores, ilmenite, and cassiterite and tourmaline.

A number of other minerals bearing tungsten are known, but they have not yet been found in commercial quantities. The names and compositions of a few are as follows:

Reinite—a ferrous tungstate, $FeWO_4$—possibly a pseudomorph after scheelite; stolzite—a lead tungstate, $PbWO_4$; raspite—a lead tungstate; cuprotungstite—a copper tungstate, $CuWO_4$; cuproscheelite—a tungstate of calcium and copper, $(Ca, Cu)WO_4$; tungstite (and meymacite)—hydrous tungstic oxide, $WO_3 . H_2O$, (119).

TESTS FOR TUNGSTEN.

1. Completely pulverize the mineral, place a small quantity in a test-tube with hydrochloric acid. Boil vigorously for fifteen or twenty minutes if hubnerite, ferberite or wolframite is looked for, or about ten minutes if scheelite is expected. A fine yellow powder, tungstic oxide, WO_3, is formed. When a small piece of tin or zinc is added, the yellow powder and the pow-

dered tungsten mineral are changed to a fine blue. The tungstic oxide is reduced by the stannous chloride to a lower hydrous oxide, W_5O_{14}. H_2O, (1). If concentrated or very strong hydrochloric acid is used the blue solution will soon change through wine color to purple-brown, and finally to brown. If dilute acid is used the blue color will last much longer. Dilute sulphuric acid may be used, but in the case of the dark tungsten ores, requires a longer time to produce the tungstic oxide. The blue color obtained by reducing with zinc or tin is more lasting than that obtained by treating with strong hydrochloric acid. If the finely powdered mineral is fused with ten to fifteen times its volume of sodium carbonate (or baking soda) in an iron spoon, and then dissolved in acid and treated with the zinc or tin, the results will be the same, but the test will be more certain, since the minerals are rather hard to break up with the acids alone.

The powdered mineral is more readily dissolved in *aqua regia* (nitric acid *one* part, hydrochloric acid *three* parts).

2. A test which has proved satisfactory with the dark tungsten ores may be made as follows: Reduce the mineral to a very fine powder and fuse with sodium carbonate (baking soda). Dissolve the mass by boiling in water, add a few grains of ammonium sulphocyanate, and heat gently to dissolve the salt. Add dilute hydrochloric acid. A bright wine-red is produced. Add tin and boil. The red disappears and is followed after a short time by a rich-green solution. The depth of the green will depend upon the strength of the solution.

3. Follow the first test until the first boiling has occupied twelve or fifteen minutes, then add a little nitric acid and boil about five minutes. Allow the yellow powder to fall to the bottom, and drain off the liquid. Add ammonia. If the yellow powder is dissolved, it was formed by tungsten. The ammonia solution may be acidified with hydrochloric acid and tin added. The blue color produced by boiling will not disappear when the solution is diluted with water.

4. The salt of phosphorous bead containing a little tungstic oxide is colorless in the oxidizing flame, but blue in the reducing flame.

OCCURRENCE OF TUNGSTEN MINERALS.

The modes of occurrence of the various tungsten minerals can best be understood by reference to typical deposits.

Scheelite: In the Cariboo district near Barkerville, B. C., a white to buff-colored scheelite of rather coarse granular habit accompanies galena, pyrite and siderite in quartz stringers in a zone from twelve to twenty feet wide in a highly altered mica schist. The scheelite, is semi-transparent to opaque, shows distinct cleavage faces, and has a dull, almost earthy luster. The scheelite at Nome, Alaska, is in a similar country rock.

In the Victorio district, near Deming, N. M., scheelite occurs with pyrite, lead minerals and hubnerite in a vein cutting limestone.

Contact deposit at Trumbull, Conn.: Scheelite occurs at the contacts of a limestone and a hornblende gneiss, where it is associated with quartz, zoisite, garnet, epidote and other minerals characteristic of contact metamorphism. The scheelite occurs mainly in the upper part of the hornblende gneiss, just below the lower contact plane, where it is irregularly distributed in grains, crystals, and aggregates as large as the fist, and forms 5 per cent. of the vein. Wolframite derived from the scheelite is also present.

In La Sorpresa mine, Spain, scheelite and wolframite occur in white quartz at the contact of Cambrian slates and granite.

As a gangue mineral: In the eastern part of Missoula Co., Mont., scheelite forms the gangue or vein matter of a gold deposit. Near Jardine, Park Co., Mont., scheelite occurs in bluish white quartz. Near Caliente, Kern Co., Cal., a rich ledge of scheelite occurs in a lead-silver mine.

Scheelite occurs in a number of placer deposits, as at Nome, Alaska, but the mineral is derived from nearby vein deposits.

Near Hill Grove, in New South Wales, scheelite occurs in numerous veins in a gneissic granite. In New Zealand, scheelite occurs in the auriferous quartz reefs of Otago and Marlborough. In Marlow township, Beauce Co., Quebec, scheelite occurs in association with specular iron, pyrrhotite, galena, chalcopyrite, pyrite, in quartz veins cutting Cambrian slates. Tungstite (or meymacite) sometimes accompanies the scheelite.

Scheelite in small quantity has been found associated with pyrrhotite, chalcopyrite, pyrite, pentlandite and various other rare minerals in the Victoria mine (nickel, Sudbury, Ontario). The country rock of the nickel deposits is norite.

Scheelite and other tungsten minerals are associated with tin ores in many tin-mining regions, such as England, Bolivia, Queensland, New South Wales, East Indies, Australia, Spain, Portugal, and Germany. In a number of these the country rock is greisen. Other minerals with which scheelite may be found are topaz, fluorite, apatite, molybdenite and antimony.

Wolframite and hubnerite: The Black Hills wolframite occurs in flat, horizontal, but rather irregular masses, intimately associated with the oxidized, refractory siliceous ores formed by the replacement of a magnesian limestone by uprising solutions along fracture lines passing from the underlying pre-Cambrian rocks up into the limestone. Before oxidation, the ore carried pyrite, fluorite, barite and occasionally gypsum. In the Tungsten Mining District southeast of Ely, Nevada, hubnerite in fine grains, with a little fluorite, pyrite and scheelite, occurs in compact quartz forming a branching system of veins cutting a granite porphyry intruding Cambrian quartzites and argillites. Wolframite occurs as a pseudomorph (replacement retaining the same crystal form) after scheelite in the Trumbull, Conn., deposit mentioned above. At Nigger Hill and Etta tin mines, in the northwestern Black Hills, wolframite is found in the pre-Cambrian rocks as a constituent of pegmatitic granites of the greisen type. In Beira Baixa province, Portugal, wolframite occurs with cassiterite, oxide of iron, pyrite, arsenopyrite and mica in a quartz gangue in schists of Cambrian age.

In northern Queensland wolframite deposits occur in granite, greisen, felsite, quartz-porphyry, chlorite schist, slate and quartzite. The gangue materials are almost as varied—including quartz, chlorite, muscovite, biotite, topaz rock, fluorspar, beryl-rock and greisen with and without quartz. The commonest country rock is granite and the commonest gangue is quartz. With the wolframite are also associated bismuth in several forms, molybdenite and minerals bearing manganese, tin, iron, copper, lead, zinc, uranium and cerium.

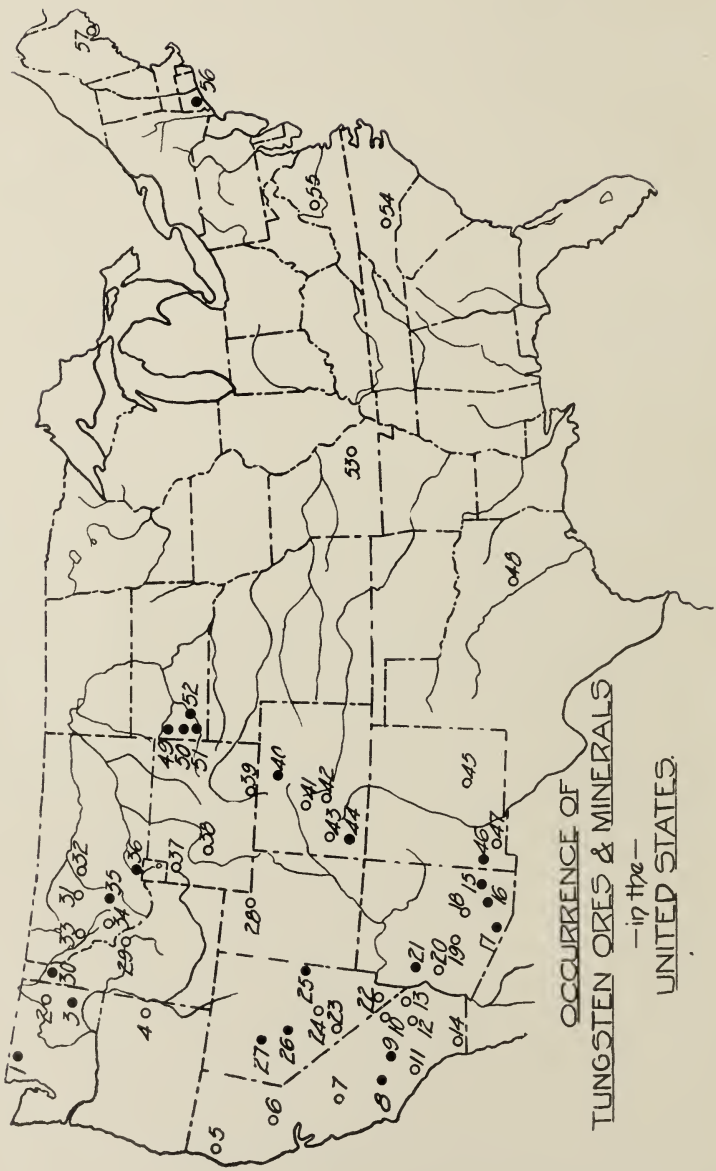
In the North Star mine, Silverton, Colorado, hubnerite, associated with fluorite, occurs in a quartz gangue carrying auriferous pyrite, argentiferous galena, tetrahedrite, chalcopyrite, sphalerite and barite. The fluorite and hubnerite are later than the main vein filling. The country rock is a quartz monzonite.

Ferberite: The Boulder deposits are rather remarkable for the almost complete absence of minerals commonly associated with tungsten ores in other parts of the world. The ore is mainly in the form of a breccia, the fragments of which include chalcedonic quartz or hornstone, dike granite and pegmatite, country rock and ferberite. The dike rock shows various stages of alteration from that in which the original character is readily made out to forms in which the original materials are almost entirely replaced by silica. The matrix is very commonly ferberite, but in that ore in which fragments of ferberite occur a matrix of crushed rock or of hornstone may partly or almost wholly replace the ferberite. Pyrite occurs in very small amount, and a rare crystal of galena is found. Fluorspar has been reported, but the writer has not seen any. There are, however, very minute cubical cavities and a few minute grains of an isotropic mineral in the silicified dike rock gangue and in the hornstone. These cavities may have been occupied by fluorite, and the isotropic grains may be fluorite. A few very small flakes of molybdenite have been found, and at one or two points near Magnolia and near Sunshine gold tellurides are associated with the ferberite.

TUNGSTEN LOCALITIES IN THE UNITED STATES.

Tungsten minerals have been reported from about sixty localities in the United States. In the following list the numbers refer to the accompanying sketch. (Plate 1.) The dots mark places which have produced ore; the circles indicate the presence of tungsten minerals—rarely in commercial quantity.

PLATE I.



Washington:

1. Near Loomis, Cascade Mts., Okanogan Co. Wolframite. Shipping. (68), (76), (93).

2. Vicinity of Deer Trail, Stevens Co. Two localities. (54), (76).

3. Cedar Canyon and Springdale District, Stevens Co. Opened up. (76).

Oregon:

4. Virtue district, east of Baker City. Scheelite in placer gravels of Cliff mine. (87).

California:

5. Eureka, Humboldt Co. Tungsten mineral not specified. (4).

6. Howard Hill, Grass Valley, Nevada Co. (86).

7. Twelve miles northeast of Raymond, Madera Co., and in southern Mariposa Co. Scheelite. (93).

8. Caliente, Amalie and Paris, Kern Co. Scheelite in a lead-silver mine at Caliente. Producing. (76), (93).

9. Randsburg and Johannesburg district in Kern and San Bernardino counties. The Atolia Mining Co. Scheelite. Producing. (76), (92), (125r).

10. Ivanpah district. Wolframite occurs. No production reported. (125k).

11. Sierra Madre, Los Angeles Co. Tungsten—minerals not specified. (4).

12. Near Kelso, on the Salt Lake Road. Scheelite. (93).

13. Manvel and Signal. Scheelite. Producing. (125r).

14. Julian, San Diego Co. Tungsten—minerals not specified. (4).

Arizona:

15. Cochise Co., six miles north of Dragoon, on the A. T. & S. F. Produced. (91), (97).

16. Whetstone Mts. Euclid Mining Co. Operated wolframite mines in 1906. (76).

17. Near Arivaca, in Santa Cruz Co. Hubnerite has been mined. (13), (91).

18. Santa Catalina Mts., near Southern Bell Gold Mine. Scheelite. (13).

19. On Buffalo-Arizona Company's property, near Phoenix. Ore reported. (76).

20. Sixty miles south of Hackberry, in Aquarius Mts., Mohave Co. (91), (125p).

21. Near Owens, 80 miles south of Kingman and 12 miles east of Big Sandy river. Wolframite. Small shipment in 1905. (92).

Nevada:

22. Mammoth District: Hubnerite. This is the place of the original discovery of hubnerite. (34).

23. Lander Co. Ore reported. (77).

24. Near Atwood, Nye Co. Tungsten ore. (125l).

25. Tungsten Mining District, 12 miles south of Osceola, in White Pine Co. Producing. (121), (122).

26. Round Mountain. Hubnerite. Producing, 1907. (13), (125m).

27. Forty miles south of Lovelocks, Humboldt Co. Wolframite. Considerable development. Shipped 1908. (92), (125w).

Utah:

28. Little Cottonwood. Tungsten ore. No shipment in 1905. (75).

Idaho:

29. Patterson Creek, Lemhi Co. Hubnerite and wolframite. (125n).

30. Near Murray, Wallace and Mullan, Coeur d'Alene district. Producing. (6), (13), (86), (101).

Montana:

31. Near Helena. Scheelite.

32. Near Neihart. Scheelite. (92).

33. Missoula Co., western part. Scheelite. Shipped in 1905. (92).

34. Near Phillipsburg. Hubnerite. (26).

35. Birdie Mine, east of Butte. Hubnerite. (125x).

36. Near Jardine and Crevasse, Park Co. Scheelite. Produced. (13), (93).

Wyoming:

37. Jackson Hole region, near Elk. Wolframite. (57).

38. Fremont county, near Shoshone. Tungsten ore. (76).

39. Holmes (near). Wolframite. (92).

Colorado:

40. Boulder Co., and adjacent parts of Gilpin Co. (117).

41. Leadville. Several mines report wolframite and hubnerite. (125y).

42. Near Salida. Hubnerite in a vein worked for copper. Scheelite also occurs in Chaffee Co. (Personal correspondence). (15).

43. Ouray County, Uncompahgre District, Royal Albert vein. (34).

44. Red Mountain and Gladstone, in San Juan region. Hubnerite. Produced. (95), (96).

New Mexico:

45. Bonito. Hubnerite occurs. (34).

46. Steins Pass, Lordsburg and Separ. Hubnerite and wolframite shipped in 1895-6. (15), (91), (93).

47. Victorio district, 18 miles west of Deming. Hubnerite and scheelite. (57).

Texas:

48. Falls County—ore reported. (77).

South Dakota:

49. Lawrence Co., Durango, Sula, Harrison, Golden, Summit and Two Strike mines produced 106 tons wolframite concentrates, carrying 38-50% tungstic oxide. (17).

50. Near Hill City, Pennington Co. Producing. (76).

51. Custer County. Producing. (15).

52. Keystone, Pennington County. Wolframite. Producing (?) (76).

Missouri:

53. Madison and St. Francois Co., in vicinity of Mine La Motte. Wolframite. (34).

North Carolina:

54. Flowe, Cosby and Cullen mines of Cabarrus Co. Scheelite with a little wolframite. (86).

Virginia:

55. Rockbridge County. (77).

Connecticut:

56. Long Hill station. (Monroe and Trumbull are included in the reference). (59).

Maine:

57. Blue Hill Bay. (34).

IMPORTANT TUNGSTEN DEPOSITS IN THE UNITED STATES.
(Omitting Boulder County, Colorado.)

Arizona: The most important producing districts have been that near Dragoon, in Cochise county, and that at Gigas, near Arivaca, in Santa Cruz county.

In the Dragoon area hubnerite occurs unevenly distributed in vertical quartz veins, of irregular width, cutting granitic, gneissoid rocks. The production has come mainly from shallow lode workings and placer washings. In the Arivaca area hubnerite is found in most of the gold-bearing quartz veins southward into Sonora. The mineral occurs in blade-like crystals, tabular masses and bunches, and is easily concentrated. Hundreds of tons of high-grade ore were mined and piled up years ago, and are still untouched.

California: The Randsburg district, mainly in San Bernardino county, has become the second largest producer of tungsten ores in the United States. Scheelite deposits are found over an area of several square miles. The deposits owned and worked by the Atolia Mining Company at Atolia, five miles south of Randsburg, are the best developed in the district. The scheelite bearing veins occur mainly in a medium-grained granodiorite in the form of a large mass or batholith intruding ancient mica and hornblende schists. On the north border of the mass, veins occur in both schist and granodiorite, and below the surface may pass from one rock to the other. The vein system occupies a zone of shearing in which the movement was localized along certain lines. The vein matter consists of crushed granodiorite, partially silicified crushed granodiorite, calcite, fine granular quartz replacing the granodiorite, crystalline quartz and scheelite. The quartz and scheelite were apparently brought up in solution and deposited at the same time.

Nevada: The Tungsten Mining District lies along the western slope of the Snake Range south of Wheeler Peak, about 45 miles southeast of Ely. The hubnerite veins are in a granite porphyry which intrudes the Cambrian quartzites and argillites flanking the range. The veins trend northeast and southwest and

pitch 55°-75° to the northwest or southeast, and range from a few inches to three feet in width. The gangue is compact quartz and hubnerite, with here and there a little fluorite, pyrite and scheelite. The hubnerite occurs: (a) irregularly distributed through the quartz, (b) in irregular masses, (c) in segregations along the vein wall. The veins were probably filled by deposition from mineralizing waters from the cooling granite porphyry.

South Dakota—Lead City, Black Hills: Wolframite occurs in flat, horizontal, but rather irregular masses, from an inch to two feet thick, and ranging in area from 20 to 30 square feet. The ore is intimately associated with the oxidized, refractory, siliceous gold ores. These ores, in their unoxidized form, consisted of secondary silica with pyrite, fluorite, barite and occasionally gypsum, and resulted from the replacement of Cambrian dolomite through the agency of uprising (thermal) solutions from the underlying pre-Cambrian schists and slates. The wolframite may be regarded as a basic phase of the siliceous ores. It also occurs as a rim around the outer edge of the siliceous ore shoots and sometimes as a cap over them. The wolframite ore is a dense, black, massive rock of fine texture, resembling a fine grained magnetite.

In the Nigger Hill and Etta tin district it occurs as a constituent of pegmatitic granites, usually of the greisen type.

A number of other deposits occur in the Black Hills region.

Colorado—San Juan: Hubnerite is found in a number of mines and prospects near Gladstone, north of Silverton; in the Tom Moore lode, one and one-half miles above Eureka, on the Animas; and in three or more properties on the slopes of Sultan Mountain. It was found in the Royal Albert vein in the Uncompahgre district, Ouray County.

The Adams claim is on the western slope of Bonita Peak, about a mile from Gladstone. The hubnerite is irregularly distributed as thin lenses, bunches and stringers in a gangue of quartz and fluorite filling a series of fissures forming a narrow sheeted zone in an altered pyroxene andesite. In Dry Gulch, a tributary of Cement Creek, below Gladstone, the Dry Gulch, Dawn of Day, Sunshine and Minnesota claims are located on a single strong lode. Hubnerite occurs in all the claims, but only the Dry Gulch and Dawn of Day show any important development. The occurrence of the hubnerite is similar to that in the Adams. A few tons of high-grade concentrates have been shipped. The Natalie and Big Colorado mines are in a gulch a short distance

southeast of Gladstone. The Natalie hubnerite is in glistening, black needles, prisms and blades in a quartz gangue. Amorphous silica sometimes forms smooth rounded surfaces over the quartz and hubnerite. The ore resembles wolframite, but the analysis (page 44) shows only 2.03 per cent. FeO. It pulverizes to a rich brown powder. The other metallic minerals of the Natalie include argentiferous galena, pyrite, chalcopyrite and free gold.

The hubnerite of the Tom Moore is in very small quantity and can not be regarded as at all promising. The North Star mine, the Little Dora vein and the Empire-Victoria vein are all on the slopes of Sultan mountain. All contain a little hubnerite. The ores include auriferous pyrite, galena, tetrahedrite, chalcopyrite, sphalerite, associated with fluorite, barite and much quartz. Hubnerite occurs associated with fluorite in the more quartzose portion of the veins, though occasionally it is in a kaolinized, disintegrated mass. Both fluorite and hubnerite are later than the main vein filling. The country rock is monzonite.

The conditions would seem to be favorable for making tungsten concentrates as a valuable by-product, but the showings, as yet, do not promise profits if tungsten alone is produced.

FOREIGN OCCURRENCES.

Australasia: Tungsten ores are mined in Queensland, New South Wales and the Northern Territory (of South Australia), and they are reported from various points in West Australia. In production the states stand in the order named.

In northern Queensland an area of 3,500 square miles contains several belts of tungsten deposits. The ore is almost exclusively wolframite, though scheelite is produced in one locality (Parada). Both lode and placer mining are carried on. Old Wolfram Camp is the most important tungsten mining centre. The commonest country rock of the tungsten area is granite, but deposits are also found in greisen, felsite, quartz-porphyry, chlorite schist, slate, and quartzite. "The gangue of the wolframite is usually quartz, but it also occurs with and without this mineral in greisen, chlorite, muscovite, biotite, topaz rock, fluorspar, and beryl-rock." In form, the ore bodies include quartz veins, large and lenticular bodies of quartz, irregular masses of chlorite, quartz and mica, and impregnations of greisen and granite. In the richest ore bodies, those of irregular form, the wolframite occurs in isolated patches or

bunches. Bismuth and molybdenum are saved as by-products. Tin is also important.

South Australia: Tungsten ores are found in the Northern Territory, and have been extensively mined during the past two years.

West Australia: Tungsten ore occurs in the Geraldton, Pilbarra, Coolgardie and Greenbush areas.

New South Wales: Scheelite is mined at Hill Grove, and wolframite in the Mole Table land. Producing areas are: Emmaville, Uralla Tuena, Baraba, and Farrington.

New Zealand, Otago: Scheelite occurs in the auriferous quartz reefs of Otago and Marlborough. The reef follows the planes of schistosity of the schists.

Tasmania: A few tons of wolframite are produced.

Europe:

Portugal produces a few hundred tons of ores annually, chiefly from the province of Beira Baixa, where wolframite occurs with tin ore, oxide of iron, pyrite, arsenopyrite and mica in quartz gangue in schists of Cambrian age. Portugal has become the largest European producer.

England: Wolframite, scheelite and tungsten ochre occur both in the mines and in the tin placers of Cornwall, chiefly in the high-level platforms of Bodmin Moor. But wolframite is the only commercially important ore. It accompanies tin and copper ores which occur disseminated through granites, quartz porphyry ("elvan") and slates ("killas"), and in minute veins in these rocks. As Camborne is the most important area, a brief description will be given. Metamorphic sediments varying in character from slates to phyllites overlying granites are intruded by greenstone sheets, and both slate and greenstone are cut by large granite masses having an average trend of 20° north of east. Cutting all these are dikes of quartz porphyry. The area is cut by many faults trending almost at right angles to the quartz porphyry dikes and the mineral lodes.

The lodes are commonly parallel to the dikes and in many instances occupy fault planes. The walls are irregular and impregnation of the country rock is common. The ore is irregularly distributed in the lodes in "bunches and pipe-like" masses, and there are many evidences of secondary enrichment. The mineral contents include, (1) the "veinstone," which may be quartz, feldspar and tourmaline and decomposition products

from the country rock; (2) the ores or metalliferous minerals, including cassiterite, pyrite, arsenopyrite, chalcopyrite, and wolframite. Locally, ores of nickel, cobalt, zinc, lead and uranium are found in the higher levels, while antimony, bismuth and molybdenum have been produced in commercial quantity. The tungsten ore is mainly wolframite, but scheelite and tungsten ochre occur. The wolframite occurs along, and on both sides of the contact between the granite and the slate. The Camborne district is the most important tungsten producer, but shipments have been made from Tavistock, especially from the Clitters mine, and from near Liskeard.

Spain: Wolframite and scheelite occur in La Sorpresa mine, in a white quartz at the contact of Cambrian slates and granite. The tin deposits of Orense and Pontevedra carry wolframite.

Austria: Produces a small tonnage annually, mainly as a by-product of the tin mining.

Germany: A few tons of tungsten concentrates are produced annually from the old tin dumps of the Altenburg district.

Italy must be credited with a few tons.

France produces a few tons.

Sardinia: Scheelite and wolframite have been found in considerable quantity.

Russia: Tungsten ore has been mined in the Ural Mountains.

Africa:

South Africa became a tungsten producer in 1906, and in 1907 shipped 211 tons, on a 60 per cent. tungstic oxide basis.

Asia:

India: Wolframite is found in the Tenasserim district of Burma, and at Agargaon.

Siam, the Federated Malay States, Singkep and Billiton, all produce a small tonnage of tungsten ore. Most of this is obtained as a by-product of tin mining.

Siberia: Hubnerite and wolframite are reported from the gold mines.

South America:

Argentina has outstripped all other South American states.

Bolivia: Wolframite is mined chiefly in the tin-mining districts of La Paz, Oruru, Potosi, and Chorolque.

Brazil: Promising deposits have been opened near Porte Alegre, South Brazil.

Canada:

Nova Scotia: Wolframite occurs at Northeast Margaree, and hubnerite at Emerald, in Inverness county. Scheelite is found in the Molega mining district, Queens county. Wolframite, hubnerite, and scheelite are found in the tin deposits at New Ross, Lunenburg county.

Quebec: Scheelite, sometimes accompanied by tungstite (or meymacite), occurs in Marlow township, Beauce county.

Ontario: Wolframite was found in a boulder on Chief's Island, Simcoe county, and scheelite has been found at Sudbury.

British Columbia: Scheelite occurs in the Slocan district and near Barkerville in the Cariboo district. Wolframite and scheelite occur on Sheep Creek, near Salmo, in the Kootenay and wolframite occurs on St. Mary's River north of Cranbrook.

Yukon: Scheelite has been found in the placers.

The world's production of tungsten ore for 1906 and 1907: The table is arranged according to production for 1907, estimated in short tons of concentrates containing 60 per cent. of tungstic oxide: (From Mineral Resources for 1907.)

Country.	1907	1906
United States	1,640	928
Queensland	703	865
Portugal	702	629
Argentine	507	326
New South Wales	451	270
Northern Territory (Australia)	443	114
England	361	304
Spain	222	222
South Africa	211	9
New Zealand	121	121
Federated Malay States	89	151
Bolivia	75	75
Austria	63	63
German Empire	57	57
Tasmania	46	22
Billiton	41	---
Italy	28	28
France	20	20
Siam	10	---
Singkep	1	---
Total	5,791	4,204

ORE-BODIES OF BOULDER COUNTY.

Country rock: The granite, gneissoid granite, and the more granitic parts of the gneiss have proved the best ground for the prospector and miner. The majority of the mines are in the granite area of the map, but a number of the good producers lie close to the contact of granite and gneiss, and in some instances the workings are almost entirely within the gneiss. It is a noticeable fact, however, that, where the veins cut the more pronounced gneiss, and particularly the schistose bands and areas of the gneiss the ore-bodies decrease in size and not infrequently the vein becomes barren. This is due to the physical rather than to the chemical character of the rock. In the deformations and faultings which prepared the openings for the ore deposits, the gneissoid granite, the less schistose parts of the gneiss and the pegmatite were intimately fractured and formed rather open breccias. On the other hand, the schistose part of the gneiss, acting more as a plastic mass, yielded by folding, crumpling and shearing, rather than by open fracturing, and, adjusting itself to the entire space available, closed up the underground water courses. In the Nederland-Beaver Creek area a number of the veins follow dikes of coarse and fine pegmatite, but the relationship is due to structure rather than to any common genesis. The fissuring now occupied by the veins—long subsequent to the formation of the pegmatite dikes—followed the lines of least resistance, which, in several instances, coincided with the dikes. In the northeastern area pegmatite is not so abundant and there are few associations of ore and typical pegmatite.

Other veins are associated with a fine grained intrusive biotite granite which forms dikes and irregular masses such as that about the Clyde Mine, a mile northeast of Nederland. In some instances, particularly in the southeastern area, this fine-grained granite shows a tendency toward the porphyritic texture, but this seems to be merely a local variation which is not characteristic. Weathering has made the porphyritic appearance more prominent in many places, while in other instances it has given the rock somewhat the appearance of a decayed greisen. The biotite has become leached and chloritized, and a chloritized kaolin occurs in grains of considerable size. In some cases the fine-grained granite seems to grade imperceptibly into the country granite. This may be due in part to contact metamorphism, for it is evident that in places, mineral changes have taken place along the line of contact, which have rendered the two rocks more alike.

PLATE II.

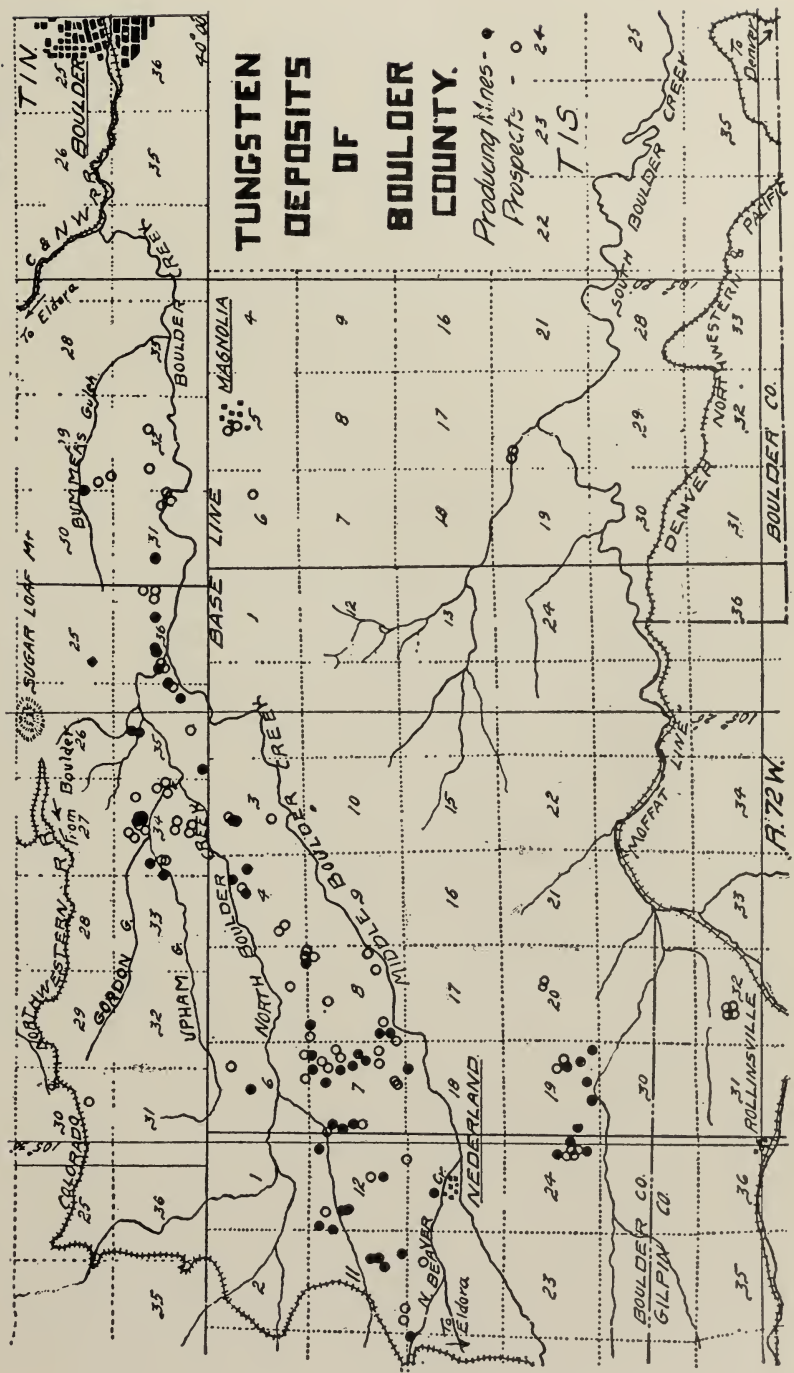


Plate I.
TUNGSTEN DEPOSITS OF BOULDER COUNTY.
Producing Mines - ●
Prospects - ○
T1N.
T1S.
R.72W.
BASE LINE
MAGNOLIA
NEDERLAND
BOULDER CO.
GILPIN CO.
ROLLINSVILLE
MOFFAT LINE
DENVER
NORTHWESTERN & PACIFIC
SOUTH BOULDER CREEK
MIDDLE BOULDER CREEK
NORTH BOULDER CREEK
BOULDER CREEK
BUMMERS GULCH
SUGAR LOAF Mt.
UPHAM G.
GORDON G.
NORTHWESTERN R.R.
COLORADO
N. BEAVER Cr.
To Eldora
To Denver
C & N.W. R.R.
BOULDER

The relationship of the veins to the dikes is the same in the fine-grained granite as in the pegmatite. The fractures occupied by the veins commonly follow one or other wall of the dike. Occasionally they split the dike and both walls of the vein are formed by the dike rock. In some cases the vein leaves the dike entirely and passes out into the country rock, usually at a sharp angle with the dike, leaving a thin wedge of country rock between. In the northeastern area the long line of mines and prospects roughly parallel to Middle Boulder and Boulder Creeks from near Castle Rock to Wheelmen is closely associated, in a large part of its course, with a narrow, but rather continuous dike of fine-grained granite. In places the entire width of the dike is occupied by the vein. In others, alteration in both the dike and the country rock has left the two quite similar in appearance.

Trend of the veins: There is no regular system of veins such as characterizes certain camps. But in the Nederland and Beaver Creek part of the field, a large proportion of the veins trend between north and east, ranging from due north to north 80° east. Very few take a course west of north. The average trend of eleven well-defined veins in the western part of the Nederland-Beaver Creek area is north 32° east, but the courses nearest to the average are: N. 24° E., N. 29° E., N. 40° E., N. 40° E. In the Upper Rogers Tract eight veins average N. 45° E., and one other has a trend N. 87° E. Fifteen veins of the Lower Rogers Tract range from N. 48° E., to N. 70° E.

In the Gordon Gulch area the general trend is north of east, but is much more nearly east and west than in the Nederland-Beaver Creek area.

The angle of dip of the veins is generally steep—often approaching the vertical, and rarely falling so low as 45°. The following are a few examples of the trend and dip of the veins: The Townlot—trends north and south, and dips 65° E., but flattens to 40° or 45°. The Conger trends N. 8° E., and dips at a variable, but always high degree, west. The Oregon trends N. 8° E., and dips at a high degree west. The Beddick trends N. 20° E. (general). The Elsie trends N. 62° E. and dips nearly 90°. The Last Chance trends N. 40° E.

VEIN STRUCTURE AND VEIN FILLING.

Outline of the stages of ore-deposition in the Nederland-Beaver Creek part of the field:

a. The first opening of the fissures, accompanied by much crushing and the formation of masses of angular fragments.

b. The silicification of the rock fragments and their partial cementation into an open breccia, and a slight local deposition of tungsten mineral.

c. The second movement of brecciation.

d. The first important deposition of tungsten mineral.

e. The third movement, crushing the breccia-ore, and mingling it with much rock matter, and in places forming a new breccia by pressure.

f. The second deposition of chalcedony-like silica. This was local.

g. The second important tungsten deposition, partially cementing the breccia. It is possible that this was a secondary enrichment. But no clear evidence was found.

h. The contemporaneous deposition of silica and tungsten.

i. Local solution of the tungsten and deposition of silica.

(j. In parts of the tungsten field slickensiding and very recent brecciation are found, showing that movement has occurred later than recognizable deposition of ferberite or silica.)

While the stages outlined above are not all evident in all the tungsten deposits, they are clearly recorded in several of those affording the best opportunity for investigation, and it seems probable that further study would show that for the Nederland-Beaver Creek part of the field the stages in the formation of the deposits were, in general, as here indicated. Owing to the closing of most of the mines before the field work of the northeastern area was completed, the ore bodies could not be studied in detail, but it is probable that the process of deposition was less complex and accompanied by fewer movements.

a Many of the first fissures followed pegmatite and biotite granite dikes while others cut the country rock. They were the result of tensional stresses, accompanied or followed by, both horizontal and vertical movements in which the dislocation was probably slight. When the movements ceased, the fissures were partially filled by loose, open masses of angular rock fragments, varying in size from mere grains to boulders. In the pegmatite dikes the crushing resulted in the formation of smaller frag-

ments than in the biotite granite dikes. The large feldspars split easily along cleavage planes, and many of the fragments contain only feldspar, while others show only quartz. But the zone of fracturing was, as a rule, narrower in the pegmatite than in the dike granite, or in the country rock.

Where the fissures have followed dikes, the position of the fissure with respect to the dike walls seems to have influenced the location of the crushing. Where the fissure is within the dike, the crushing is generally on both sides of the opening, but where the fissure follows one of the dike walls, the dike rock is usually much more crushed than is the country rock. This may be due in part to the yielding of the country rock without marked fracturing along the more or less distinct foliation planes, or it may be due to the greater strength of the country rock.

b Silica-bearing waters, probably at high temperature, circulated through the rock fragments in the fissures. By a process of replacement the feldspars and the biotite of the rock fragments were slowly dissolved out, and silica in the form chalcedony-like quartz or hornstone was deposited in their place. By this substitution many of the smaller rock fragments were almost entirely robbed of their feldspar and biotite, and are not easily distinguished from the hornstone. In others, an occasional feldspar and a few semi-transparent quartz grains remained to show the original character of the rock. The larger fragments still retained cores of unaltered rock surrounded by shells, from which these minerals were more or less completely removed. That the rock fragments were fresh when the process of change began is probable from the facts: that the replacement probably took place below the zone of weathering; and that fresh feldspars and biotite are still found in the cores of the large fragments. These silica-bearing waters also deposited hornstone between the rock fragments and partially cemented them into an open breccia. The completely silicified rock-fragments and the silica cement between the fragments are a part of the hornstone ("hornblende" of the miners). It is probable that a part of the pegmatization mentioned in the discussion of pegmatites took place at this time, and that the secondary feldspars observable in some parts of the area represent the crystallization of the feldspars removed from the rock fragments. Locally, a small deposition of ferberite accompanied the silification.

c The breccia in the fissures was still very open when the second movement occurred. This time the vein breccia with the

local deposits of tungsten, more dike rock, and in places country rock, were crushed and mingled in a new mass of fragments, ready to be cemented into a new breccia. This movement was accompanied by considerable vertical displacement and dragging along the walls of the veins.

d The first important deposition of tungsten followed the second crushing movement, which seems to have been more profound than the preceding. The character of the waters which followed it was quite different from that of those which followed the first. In place of an overload of silica, these were heavily charged with tungsten salt, and either through changed physical conditions as they rose to the surface or through mingling with other solutions—probably carrying ferrous iron, ferberite was deposited. In places silica accompanied the deposition of ferberite in the earlier part of the process. This may have been the overlapping of the two processes of deposition, since the earliest tungsten precipitation began before the second movement as mentioned above.

In less open parts of the fragmental mass in the fissures the ferberite formed a complete cementation, but in the more open parts the walls of the openings were crustified and many vug-like cavities were formed by the connecting crusts of ferberite. Locally, silica deposition followed the ferberite before the third movement took place, but this was not general.

e The third movement crushed the vein filling and added dike-rock or country-rock to the fragmental mass. It now consisted of the silicified dike-rock or country-rock in varying amount, chalcedonic quartz and the ferberite. Locally this movement caused the formation of a pressure-cemented breccia. Probably silica aided the cementation.

f The second considerable deposition of hornstone silica followed the third movement and partially recemented the fragments, but this was only local.

g The second important tungsten deposition followed the third movement, and in places completed the cementation, but much open ground still remains in the veins, and vugs lined with ferberite druses are very common. It is possible that this was a secondary enrichment in which the tungsten of the higher parts of the vein was dissolved and carried down and deposited at greater depth. But no clear evidence was found in support of this. The presence of rich ore at the surface, and much float in the mantel rock are opposed to this view.

h The contemporaneous deposition of silica and tungsten.

i Local solution of the tungsten and deposition of silica, possibly producing secondary enrichment is quite noticeable.

PLATE III.

Fig. 1—Elsie Mine. Fig. 2—Mammoth Mine, Beaver Creek. Breccia ore, consisting of fragments of dike rock and country rock cemented by ferberite.

Fig. 3—Conger. Fig. 4—Townlot. A breccia showing fragments of ferberite. See fu'ler d-scription of plates.

The ores: The ferberite occurs in three rather well-defined forms, which, however, frequently grade into one another. These are: 1. Well crystallized crusts and layers covering the surface of rock and hornstone fragments and cementing them into a rather open breccia; 2. Massive granular ore showing few or no crystal faces and occurring as more dense seams and masses in the wider and less brecciated parts of the vein; 3. The highly siliceous ore in which ferberite in fine grains—sometimes showing crystal forms—is scattered through hornstone or cryptocrystalline quartz. This type may occur in any of the mines, but was probably most abundant in the earlier workings of the eastern side of the region. It varies widely in its ferberite content from masses in which hornstone is but a scanty cementing matrix to those in which there is but a meager sprinkling of minute ferberite grains in the hornstone.

DESCRIPTION OF PLATES.

Plate III, Figs. 1 and 2.—A very common type of ore—that formed by the cementation of rock fragments by ferberite. In these specimens there are fragments of both the dike rock along which the vein is formed, and the country rock cut by the dike. This is common when the vein follows one wall of the dike. The dike rock is a quartz-rich granite in which the original minerals are still visible in spite of a considerable development of second ary quartz and the alteration of a part of the biotite to muscovite. Some of the fragments have lost much of the mica and feldspar from their outer borders. The country rock is a fine grained gneissoid, or almost schistose rock, showing many small flakes of biotite. In some of the fragments, ferberite fills cavities formed by the solution of some of the rock-making minerals. The cementation by the tungsten ore was incomplete and vugs lined with ferberite are shown. The specimens are from the Elsie and Mammoth mines on Beaver Creek.

Figs. 3 and 4.—These specimens are breccia-ore of different character from that shown in Plate III. It is the result of one of the later movements—the third—and contains the products of earlier movements and earlier depositions. There are fragments of country rock, of hornstone, of pegmatite, and of ferberite. It is almost an auto-breccia—a breccia in which there is no distinct matrix—but a later deposition of ferberite has filled a few openings left by the crushing and squeezing. The country rock was much altered before the movement, and had lost a large part of its feldspar, while that which remained

was kaolinized and now forms a dense, very fine-grained matrix for the quartz grains. This type of ore is common in the Nederland-Beaver Creek part of the area.

PLATE IV.

Fig. 5—Townlot Mine. Same general features as Figs. 3 and 4, Plate II, but the breccia is more open.

Fig. 6—Drusy ore from Elsie Mine.
Fig. 7—Drusy ore from the Grayback.

Plate IV, Fig. 5.—This specimen from the Townlot mine shows the same general features as are brought out by Plate II,

Figs. 3 and 4, but the breccia, while finer, is more open and contains more seams of ferberite deposited after the brecciation.

PLATE V.

Fig. 8—Home Run. Figs. 9, 10—Boulder Falls. Fig. 11—Rogers Tract. See description of plates.

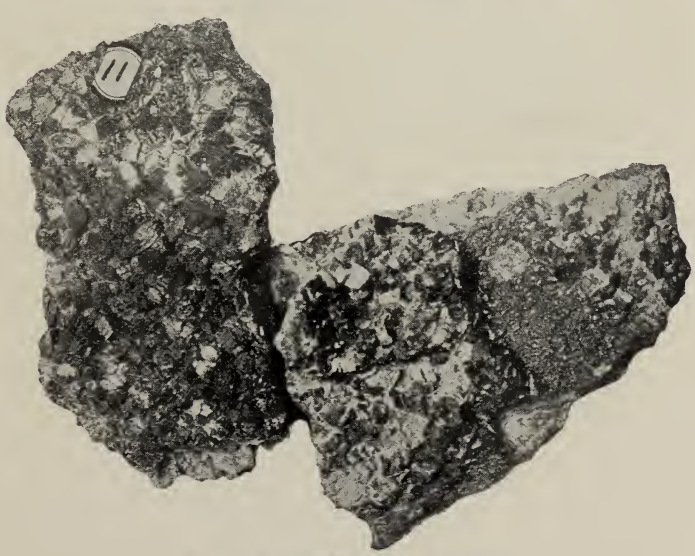


Fig. 11 A—Crystallized ferberite.

Plate IV, Figs. 6 and 7.—These specimens from the Elsie and the Grayback show the drusy linings of cavities. The rock-frag-

PLATE VI.

Fig. 12—Shows contemporaneous deposition of quartz and ferberite.

Figs. 13 and 15—Clyde Mine. Fig. 14—Beddick Mine. See description.

PLATE VII.

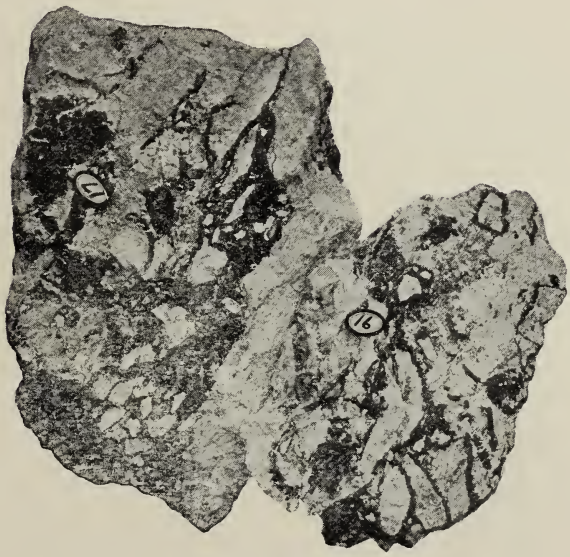


Fig. 16—Conger.
Fig. 17—Townlot.

Fig. 18—Conger, reduced one-half.

ments in 6 include both country rock and pegmatite, while those in 7 show highly silicified country rock and hornstone.

Plate V, Figs. 8, 9, 10 and 11.—Figure 8 shows a piece of ore from the Home Run mine of the Crucible Steel Company. The rock-fragments are fragments of the country rock, and many of them are so completely silicified as to be almost indistinguishable from the hornstone. Figures 9 and 10 show ore from Boulder Falls, and Figure 11, ore from the Rogers Tract. These ores present a breccia of dike rock, country rock and hornstone, with a ferberite cement. The ore shown in Figure 9 is from Boulder Falls, and consists of a breccia of dike rock fragments, many of which are so highly silicified as to be almost indistinguishable from the hornstone. In Figures 10 and 11 the dike rock fragments are but slightly silicified, though biotite is almost absent.

Fig. 11 (lower) shows crystallized ferberite.

Plate VI, Fig. 12.—Very open ore, showing dike fragments varying from slight to complete silicification. The ferberite cement is also highly siliceous and films of quartz cover the drusy ferberite in some of the openings. Slickensiding shows movement since the deposition of the ore.

Fig. 13.—A breccia of hornstone, highly silicified dike rock and ferberite, with a small amount of cementing silica. The brecciation followed the deposition of ferberite.

Fig. 14.—A stringer of breccia ore in pegmatite. The rock-fragments are highly silicified pegmatite, coated with drusy ferberite. Hornstone has completed the cementation.

Fig. 15.—A stringer of ferberite between a wall of altered pegmatite and a wall of hornstone. The dividing line between the ferberite and the hornstone is just above the number.

Plate VII, Fig. 16.—A breccia of hornstone and dike rock in varying stages of silicification. The last event was the deposition of drusy quartz and secondary feldspar.

Fig. 17.—A breccia of kaolinized and talcose dike rock with a ferberite cement.

Fig. 18.—A stringer of breccia composed of hornstone, pegmatite and ferberite, reduced one-half. The last event was ferberite deposition along the fissure walls. A previous movement brecciated an earlier deposition of ferberite.

PLATE VIII.

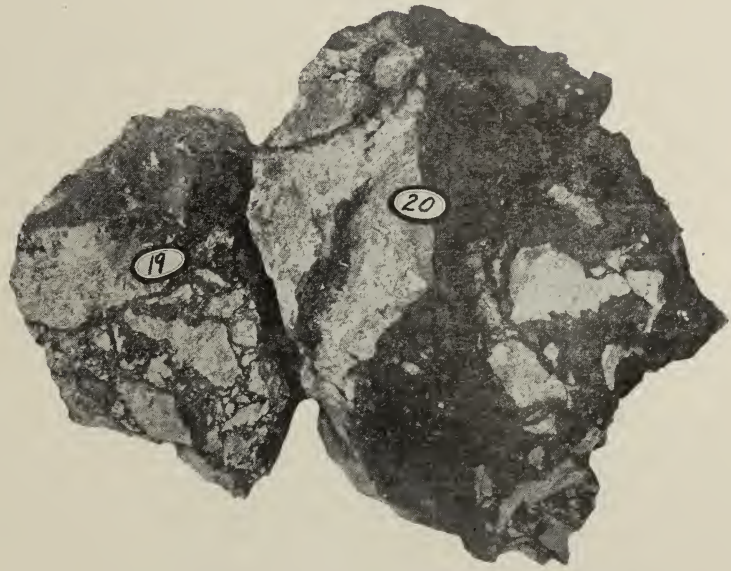


Fig. 19—Colorado Tungsten Corporation No. 4.
Fig. 20—Grayback Mine.

Fig. 21—High-grade ore from various mines.

Plate VIII, Fig. 19.—Dike rock—much decayed—cemented by crystalline-granular ferberite.

Fig. 20.—Breccia of altered country rock cemented by granular ferberite.

Fig. 21.—High-grade ore from various mines.

Plate IX, Fig. 22.—Crystallized ferberite from Lone Tree mine.

PLATE IX.

Fig. 22—Crystallized ferberite, Lone Tree Mine.

Fig. 23—Conger and Beddick shaft houses.

Fig. 23.—Conger and Beddick shaft houses.

Gangue: In the ores of the first two types the gangue materials depend largely upon the character of the rock in which the vein is formed. If the vein is in pegmatite the gangue may include fragments of the pegmatite, together with more or less deposited hornstone, a part or all of which may be in angular fragments. In the granite dikes and masses, fragments of granite will take the place of the pegmatite, while in the veins cutting the granite and gneissoid granite these rocks furnish their share of the gangue. In the shallower workings much of the rock matter is highly altered. In places this alteration has gone only to the extent of the kaolinization of the feldspars and the removal of the dark minerals or their alteration to a pale green talcose chlorite. Such ores are the most easily concentrated. In other cases the alteration has included the replacement of the greater part of the feldspar by cryptocrystalline quartz or hornstone almost indistinguishable from the hornstone deposited from solution. Below the surface weathering, the rock fragments are fresher, silicified fragments are also numerous, and hornstone may be objectionably plentiful. These last conditions increase the difficulties of concentration and make a high percentage saving very hard to secure.

Other vein minerals: The Boulder veins are unusually free from the minerals which commonly accompany tungsten ores. *Scheelite* is occasionally met with in the form of beautiful druses of dull honey-yellow crystals having perfect pyramidal terminations. *Pyrite* occurs in very small amount in the gangue, but rarely, if ever in the ferberite. The amount is so small that many analyses do not show even a trace of sulphur. *Galena* is a very rare mineral in the tungsten veins, and when found is generally in minute cubical grains except in one of the tunnels near Magnolia where an appreciable quantity occurs. *Sphalerite* is associated with the galena near Magnolia, and is reported in minute quantity from one or two other localities. *Molybdenite* in minute flakes is found very sparingly in the gneissoid granite, but is exceedingly rare. A specimen of ore from the Clyde mine shows a small flake or two. *Magnetite* forms small, irregular grains and imperfect crystals in both the pegmatite and the granite dikes, but the amount is very small. Most of the ore shows a very little magnetite, but it is almost impossible, even with a very weak magnet, to get a sample which will not react for tungsten. *Fluorite* has been reported, and is possibly locally present in very minute grains in both the hornstone and silici-

fied dike rock, but it has not been possible to isolate it. Minute hollow cubes may have contained fluorite, and a rare isotropic grain in the gangue materials may be fluorite. Ferberite is found with the telluride ore in the Graphic mine at Magnolia, and a mine near Sunshine shows sylvanite associated with ferberite. The Wheelmen Tunnel—driven for gold—shows both ferberite and sylvanite. While the relative age of the ferberite and sylvanite is not always clear, specimens of the Magnolia ore leave little doubt that so far as the occurrences there are concerned, the telluride is older. Porous quartz contains a sprinkling of sylvanite well below the surface, while a crust of drusy ferberite covers the surface. The ferberite contains no telluride. The relations in the Wheelmen Tunnel appear to be much the same. Secondary *feldspar* having the form and appearance of adularia occurs in groups of tabular and prismatic crystals in a few places.

MINING.

In the early days of tungsten mining in Boulder County open pits and trenches were numerous, and in places "gopher mining" for float was profitable. At present the larger mines are well-equipped and well managed. Leasing is very common, especially on those tracts held under homestead entries. In many instances this method has proved profitable to both owner and leaser.

CONCENTRATION.

Mills: There are five mills in the district for the treatment of tungsten ores. With one exception these are partially or wholly made-over gold and silver mills. Experimenting in various lines has suggested many modifications and improvements, and several of the mills have reached a creditable degree of efficiency considering the difficult character of the tungsten ores. The Wolf Tongue mill at Nederland has treated the Company's own ores and has of late been the largest handler of custom work. The Cardinal mill at Cardinal has treated mainly the ores of the Cardinal Company. The Clarasdorf mill, below Nederland, was built by the Philipp Bauer Company to treat the ores of the Rogers tract which they held under lease. The Primos mill at Primos in the northeastern area has handled the Stein-Boericke production and a good deal of custom ore. The Lehigh Tungsten Mining and Milling Company has remodeled the old Coburn mill on Boulder Creek, but it has not yet treated

PLATE X.

Primos Mill, Primos.

Cardinal Mill, Cardinal.

PLATE XI.

Wolf Tongue Mill, Nederland.

Clarasdorf Mill.

much ore. The Boyd mill in Boulder was used by the Colorado Tungsten Corporation, both for its own and for custom ores. A few hundred tons of ores have been treated by Henry E. Wood at his plant in Denver, and other mills have treated small quantities from time to time.

Difficulties: The concentration of the Boulder County ores presents some difficult problems. Ferberite is a rather soft mineral with one perfect cleavage, and generally one or more prominent partings. As a result the mineral is extremely friable even in the massive and massive-granular forms. Much of the ferberite was deposited as aggregates of loosely arranged crystals and crystal grains, forming crusts over the surfaces of rock fragments. One crust succeeded another until in many places the opening was filled. In other places the cavities remained open, but the walls were lined in the same manner. The crystal grains composing these crusts average not more than one-eighth of an inch in length and about one-sixteenth of an inch in diameter. In much of the ore where the crust is broken the crystal grains are easily separated from one another. When to this ready crumbling of the mass is added the extreme friability of the grains and crystals themselves, it is easy to understand the excessive sliming. The finer parts of the slimes form an almost impalpable mass which when stirred in water gives it an inky appearance, and the water remains turbid for ten days to two weeks. To save these slimes is one of the difficult problems with which the tungsten mill-man has to contend. As a result of the metallurgical methods now used in the preparation of metallic tungsten and ferro-tungstens, there seems to be but a limited demand for non-concentrated high grade ore. This makes it necessary to concentrate even the high grade ore, and consequently adds to the loss, by disproportionately increasing the slimes. The Primos Mining and Milling Company (formerly the Stein-Boericke and Cardinal Companies) sorts rather carefully, sacks and ships ores running twenty-five per cent. or over, and the Wolf Tongue Company ships ores exceeding thirty-five per cent. of tungstic oxide, but other producers have not been so favorably situated in this respect.

Another difficult problem is the successful treatment of the highly siliceous ores. In almost all the tungsten mines, there is a certain amount of highly siliceous ore consisting of minute grains of ferberite in a matrix of chalcedonic quartz or hornstone. The percentage of ferberite varies widely. Outside of certain

limited areas this type of ore is fortunately not very abundant, and rarely amounts to twenty per cent. of the product. Various methods of treatment have been tried, but none has given entirely satisfactory results. Even very fine crushing leaves a large part of the ferberite with particles of quartz attached. In concentrating, these grains consisting of quartz and ferberite will be disposed of according to their specific gravity. Those in which the quartz is largely in excess will go with the tailings and ferberite will be lost, and those in which the ferberite is abundant will go with the concentrates and help to make a low grade product.

In discussing with the mill-men the methods of concentration best suited to the ferberite ores, a number of questions have arisen. Some of these are as follows:

(1) Is the stamp mill the best means of crushing the ores?

(2) Would coarse crushing the unsorted ore, jigging and regrinding (or stamping) the tailings pay?

(3) Would close sorting and separate treatment of the higher grade ores result in an increased saving which would pay the extra cost?

(4) Would chemical treatment of the low grade and the highly siliceous ores be feasible?

(5) If direct chemical treatment of the low grade and highly siliceous ores is not feasible, would it be possible to treat a low grade concentrate from them?

(6) Is magnetic separation feasible?

The writer does not pretend to be a mill-man, and his observations have not the backing of practical experience. But a few things are certain. Ferberite is exceedingly friable, and a large proportion of the particles into which it breaks are thin and flat—the best possible form to remain a long time in suspension whether on the tables or in settling tanks. Its friable character is responsible for unavoidable sliming, and its high specific gravity tends to keep it longer in the mortar, and to bring it under the stamps more frequently. The vertical screens in use are unfavorable for the quick escape of the pulp. The result is that a large part of the ore is reduced to a very fine slime. Again, much of the gangue is hornstone and highly silicified country rock which are anything but friable, and are not readily crushed to pass the screen. The rock grains aid in reducing the ore and so increase sliming.

Various tests of concentrates have shown the extreme fineness to which the ferberite is reduced. The following are given as examples, and they do not differ in any important way from the average results:

a Sample of 4 pounds from Wilfley tables:

58.57%	passed	a	150-mesh	sieve.
77.14%	"	"	100-mesh	"
82.85%	"	"	70-mesh	"
94.28%	"	"	40-mesh	"
99.28%	"	"	20-mesh	"

The discharge from the stamps in this mill was through a vertical 12-mesh screen. The sample did not contain the saving from special slimers or from stationary canvas.

b Sample of 3 pounds of mixed concentrates:

59.4%	passed	a	150-mesh	sieve.
78.9%	"	"	100-mesh	"
83.0%	"	"	70-mesh	"
94.1%	"	"	40-mesh	"
99.2%	"	"	20-mesh	"

A few ounces of clean concentrates which passed a 100-mesh screen were thoroughly shaken up in a gallon bottle of water and the bottle was allowed to stand. At the end of two weeks the water was still turbid, and when filtered yielded a perceptible amount of ferberite slime.

A method of crushing by which the fines would be at once screened out and carried beyond the reach of the machine would prevent a large part of the sliming. If the stamp mill is used, inclined screens would aid in this. The ferberite ores are in several respects similar to the zinc and lead ores of the Joplin District. Ferberite is probably a little more friable than galena. Much of the gangue of the Joplin galena (and zinc blende) is chert, and therefore very similar to the more siliceous gangue of the ferberite. The Joplin method of coarse crushing by means of a Blake (or similar machine), then screening, and roll-crushing the oversize and jigging the entire product removes at once a very large proportion of the values and correspondingly reduces sliming. This would be equally true of the tungsten ores. The tailings could be reground to the size made necessary by their character. But this also should be done in a mill which would at once release the fines.

Separate treatment of the high grade ores would undoubtedly reduce sliming, since a very large part of the values could be removed after coarse crushing.

The chemical method of treatment is as follows: The pulverized ore or concentrate is mixed with soda ash and fused. Under proper conditions a sodium tungstate is formed and the extraction is complete. The mass is dissolved in water and separated by filtration from the oxides of iron, aluminum, manganese and silicon. The addition of hot acid in excess precipitates tungstic acid, H_2WO_4, which separates as a yellow powder. This is washed from soda salts, and dried. In drying, water is given off and tungstic oxide, WO_3, remains.

So far as the composition of the Boulder county ores is concerned, there is nothing to complicate the process, but to treat the raw ore in this way would require a very large amount of soda ash. A low grade concentrate could be formed from the ore, and this could be treated more cheaply. Highly siliceous concentrates and ores are treated by this method in Europe.

The magnetic separator is successfully used on the complex tin-tungsten ores of Cornwall. There should be no great difficulty in applying this to the simple Boulder county ores, which contain practically no metallic mineral except the ferberite. Mr. Henry E. Wood has successfully applied this method, but regards it as better suited to the treatment of water-made concentrates than to the treatment of raw ore. Tests made for the writer on ores from Gordon Gulch and Boulder Falls showed a very perfect separation of material rejected by a 60-mesh screen. But with the pulp which passed the 60-mesh screen, the separation was not so perfect—rock powder came over with the ferberite. Coarse crushing would seem to be desirable for this method also.

The methods of concentration in use in the tungsten field are illustrated by the following examples:

1. *The Boulder County Mill of the Primos Mining and Milling Company:* The ore that passes 1½"-grizzlies goes to the stamp feed bin, while the over-size goes to a Blake crusher, and from this to the feed bin. The stamps weigh 750 pounds and have a drop of 6 inches seventy times per minute. The pulp passes from the mortar by a 12-mesh screen and is conveyed to Wilfley tables which recover about 70 per cent. of the total saving. The overflow goes to classifiers which make three sizes and pulp. The coarsest goes to a Frue vanner with a corrugated belt; the

middlings and fine go to Frue vanners with smooth belts. The overflow from the last two tables goes by pump to a V-shaped settler, from which the pulp is delivered to four Frue vanners with eggshell belts. The overflow from these goes to stationary canvas tables 12′ by 40′ with a slope of 1 to 12, and from these to another set of the same form and size. The sand from the corrugated Frue vanner goes to a Huntington mill, where it is reground to pass a 60-mesh sieve and is delivered to the canvas tables.

2. *The Clarasdorf mill of the Phillipp Bauer Co.:* The ore goes to a Traylor crusher, from which it falls onto a 16-mesh screen. From this point it is a wet process. The over-size passes through a Hodge crusher, then to rolls, and the product returns to the screen. The pulp from the screen goes to the first Wilfley table, and the oversize returns to the rolls. The tailings from that part of the table nearest the concentrates are reground in triplex rolls to pass a 40-mesh screen, and with the overflow from the Wilfley pass to a Traylor classifier, which makes four products. The coarsest—mainly about 40-mesh—goes to the second Wilfley, the intermediate—mainly about 60-mesh—to the third, and the finest—mainly about 80-mesh—to the fourth Wilfley. The slimes are treated on two Traylor slimers.

3. *The Colorado Tungsten Corporation's mill (the Boyd Mill, Boulder):* The equipment consists of: A jaw crusher, ten 1,000-pound stamps, four standard Wilfley tables, two Wilfley slime tables, eight Monell slime tables, and stationary canvas. The mines of the company furnished ores of two rather distinct types. For one of these a 16-mesh screen was used, and for the other a 20-mesh screen.

The pulp was classified and passed to the four standard tables. The coarse tailing from the first table, carrying about 0.4 per cent. of tungstic oxide, was discarded. The tailings from the second table were reground. The tailings from the third and fourth tables, mixed, went to four Monell tables. The tailing from these went to a settling spitzkasten, from which the coarse material went to two more slime tables, and the slime to the stationary canvas. The tailings from the last two tables went to another large settling and sizing spitzkasten, from which the finer deposit went to two or more slime tables, and the overflow to the stationary canvas. There were many changes, from time

to time, in the methods of classification and distribution, but the above is the plan during the last month's operation.

The mill practice of the Atolia Mining Company, San Bernardino Co., Cal., working on scheelite ore, is as follows: The ore is fed into a Blake crusher, from which it passes by an automatic feeder into a Huntington mill and is crushed to 20-mesh. It then passes to Frue vanners. The high-grade ore is sorted, cobbed and sacked. (125r).

Australian method: Stamp crushing is used at Koorboora on wolframite ore running 4 per cent., but the Huntington mill is more generally used (1906), and it is believed that it causes less sliming.

Cornish tungsten ore dressing: At the East Pool, Clitters and South Crofty mines, all of which are relatively rich in wolframite, magnetic separators have been installed to remove the wolframite. The East Pool ore carries cassiterite, arsenopyrite, wolframite, and chalcopyrite so evenly distributed in the veins as to make hand sorting impossible. The pulp from the stamps is classified into sands and slimes. The sands go to Frue vanners or to Wilfley tables (preferably the latter on account of their greater speed). The concentrates contain the tin ore, wolframite and arsenopyrite, while a middling product contains the chalcoprite and some tin ore. After being calcined to remove the arsenic, the concentrates are classified, and the sands are passed over Wilfleys which yield a product containing about three ports of tin ore to one of wolframite, and about five per cent. of iron oxide.

The slimes from the first classifiers go to rag frames and the product of these passes over Acme tables, from which the concentrates go to the calciner. The calcined residues pass over Acme tables. These concentrates and those from the sand are leached with sulphuric acid, washed, dried, and passed through a Humboldt-Wetherill magnetic separator where a conveyor belt carries the material under a magnet strong enough to remove the iron oxide, but too weak to affect the wolframite. The remainder, containing tin ore and tungsten ore, passes on to a stronger magnet which removes the wolframite. The tin ore and other nonmagnetic materials are left. The object of the sulphuric acid leaching is to prevent tin ore from adhering to the wolframite and passing into the tungsten concentrates in the magnetic separator.

The Elmore vacuum process has been installed at the Dolcoath mine, but the ores contain very little tungsten.

Sale of ore and concentrates: The concentrates (and high-grade ores) are sold by the "unit" of tungstic oxide, which is one per cent. of a short ton, or 20 pounds. At present the standard concentrate carries 60 per cent. of tungstic oxide (commonly called "tungstic acid"), and must not exceed 0.25 per cent. phosphorus, nor 0.01 per cent. sulphur. Concentrates falling below this standard are penalized a few cents for each per cent. they fall below this figure in tungstic oxide, and for any excess of phosphorus or sulphur. A bonus is sometimes allowed on concentrates carrying over 60 per cent. of tungstic oxide.

POSSIBLE EXTENSION OF THE AREA.

Rocks of the same types, and in the same relationship as those of the tungsten area occur far to the north and to the south. To the north, however, there is a gradual increase in the metamorphic structures such as the gneissoid and schistose which, when pronounced, seem to be unfavorable to tungsten deposition. To the south, in Gilpin county, granites and gneissoid granites prevail for some distance, and are cut by pegmatite and granite dikes of the same type as those of the known tungsten area. While the gold and silver deposits and the tungsten deposits are not intimately associated, the two seem to conform roughly to the trend of the belt of intruded porphyries which extends from the middle of Boulder County in a southwesterly direction into Gilpin, Clear Creek, Summit and Lake counties. Tungsten is known within this belt in Boulder, Gilpin and Clear Creek counties.

Future of the district: The present development offers but few data on which to base opinions as to the future of the deposits. The workings are shallow, the ore is distributed along the veins in bunches and pockets or rarely shoots, and up to the present nothing has occurred to suggest that the downward distribution is less regular than the lateral. In fact, a considerable number of the best ore bodies have had greater vertical than lateral dimensions. This is natural when it is remembered that the deposition took place from uprising solutions, and not from solutions moving mainly in a horizontal direction. The deepest workings in the camp are showing ore bodies of dimensions and quality quite equal to those of any yet discovered.

PRODUCTION.

The preparation of a satisfactory statement of the production of the district has proved a very difficult task, but the producers have very kindly placed their mining and milling records at the disposal of the Survey. These have been compared, checked and arranged, and it is believed that the following table is reasonably accurate:

		Tons.	Average price per unit.	Value.
1900	High-grade ore, 63% WO_3	40	$1.30	$ 3,216.00
1901	High-grade ore and cencentrates, averaging 65% WO_3	65	2.25	8,775.00
1902	Ores and concentrates	166	2.50	24,900.00
1903	Mainly concentrates	243	2.50	36,317.00
1904	Ores and concentrates, averaging about 55% WO_3	375	5.50	125,000.00
1905	Mainly concentrates	642	6.00	231,120.00
1906	Mainly concentrates	789	6.5[illegible]	309,603.00
1907	Mainly concentrates	1,146	8.33	573,643.00
1908	High-grade ore 180; Concentrates 407	587	----	164,220.00

CHAPTER III—TECHNOLOGY AND USES OF TUNGSTEN.

THE METAL AND ITS METALLURGY.

The metal: There is still a notable lack of agreement among chemists regarding the properties of tungsten. The statements following are compiled from the latest publications. Metallic tungsten is generally produced in the form of a black or grayish-black powder. The fused metal is slightly darker than metallic zinc, and is distinctly lustrous. It is brittle, and non-ductile (some say ductile and malleable), but may be welded, filed and forged. Sulphuric and hydrochloric acids attack it slowly, nitric more vigorously, and a mixture of nitric and hydrofluoric acids readily dissolves it. Aqua regia oxidizes the powder form, but does not act upon the fused metal. Under ordinary atmospheric conditions it is very slowly oxidized, but at red heat it is rapidly changed to tungstic oxide. The fused metal has a specific gravity variously estimated from 16.6 (Stavenhagen), to 18.7 (Moissan), and 19.13 (Remsen). The melting point is placed at 2,800° C. by Wartenberg, but as high as 3,080° C. by Waidner and Burgess of the Bureau of Standards, Washington.

Metallurgy of tungsten: The following three examples may be regarded as representing the methods of obtaining tungsten from its ores: I. The ore is ground to pass an eight or ten-mesh sieve, and is brought to a cherry-red heat and fused with sodium carbonate (soda-ash). The sodium tungstate thus formed is dissolved in boiling water, filtered from the solid impurities, and treated with hot hydrochloric acid (or nitric), in earthen vessels. This precipitates tungstic acid, H_2WO_4. The liquid is drawn off and the tungstic acid is washed to remove sodium salts, and is then converted into tungstic oxide by drying. The dry oxide is mixed with pure carbon and placed in crucibles and heated to a very high temperature in a gas furnace. The carbon and the oxygen of the ore unite and pass off, leaving a black or gray-black metallic powder, which usually contains a small amount of carbon.

2. The tungstic oxide is produced by the same method, but the reduction with carbon is effected in an electric furnace. This method is said to produce a metal quite low in carbon.

3. The pulverized ore is mixed with pure carbon or placed in carbon-lined crucibles, and reduced in an electric furnace. The impurities, chiefly iron and manganese, and the oxygen unite with the carbon, and metallic tungsten is left.

Other methods, some of which have been used on a commercial scale, are:

1. The tungstic oxide is reduced in a current of hydrogen, which unites with the oxygen of the oxide, forming water and leaving a black powder of metallic tungsten.

2. The Goldschmidt or alumino-thermite process: The oxide of the metal is mixed with finely powdered aluminum and a readily ignited substance such as barium peroxide, in refractory crucibles. The mass is ignited and the intensely heated aluminum unites with the oxygen of the tungstic oxide, and the heat of the reaction forms a metallic bath in the crucible. The aluminum is oxidized to the form of corundum, (Al_2O_3). By proper adjustment of the charge the ore is completely reduced and the aluminum is entirely oxidized. This produces a carbon-free metal.

3. The tungstic oxide is mixed with powdered zinc and heated to redness until the zinc is distilled off. The mass is freed from zinc oxide by hydrochloric acid, and from the remaining tungstic oxide by sodium hydroxide.

4. Powdered tungsten, powdered manganese, tungstic oxide and manganese dioxide are mixed, compressed and heated in a stream of hydrogen. A mass of tungsten and manganese (not strictly an alloy) is formed, from which the manganese is removed by acids.

5. Powdered tungstic oxide is heated with one-tenth its weight of sugar charcoal in the electric furnace. With care, this yields an almost carbon-free metal.

6. Tungsten concentrates are reduced to lower oxide form by means of carbon in an electric furnace. Silicon carbide is added and the reduction is completed. (Becket process.)

7. The Greene and Wahl ferro-silicon method has also been used.

USES OF TUNGSTEN AND TUNGSTEN COMPOUNDS.

Introduction: Pure metallic tungsten is but little used in finished industrial products. But, alloyed with other metals, and in various chemical compounds, the use of tungsten has recently become important. Many of its physical and chemical properties have been known for decades, but until recently the supply

of tungsten ore was so uncertain and irregular that there has been little inducement to develop industries dependent upon a supply of tungsten. The discovery of the Australian deposits and those of the U. S. has given manufacturers reasonable assurance that an increasing demand would be met.

The certainty of a supply of ore encouraged a more thorough study of the metal and its possible uses. And the development of the gas and electric furnaces for metallurgical purposes made the production of metallic tungsten much less expensive. As a result, the demand for tungsten has increased very rapidly, and the metal has taken its place as a necessary factor in a number of important industries.

Tungsten is employed chiefly in the following forms:

The metal is used: (1), for the making of alloys with various metals, such as iron, aluminum, nickel, copper, titanium, tin and others. (The alloys will be discussed below.) A small amount of tungsten is mixed with the magnetite in the electrode of the "magnetite arc" lamp; (2), for filaments in the tungsten incandescent lamp, and has been tried as an electrode in arc lamps.

There are at least a hundred patents recorded for the preparation of incandescent lamp filaments in which tungsten is the important metal. In most of these, metallic tungsten powder forms part of a plastic mass or paste, which is made into a filament by forcing it through a die having an opening of the required size. The substances used for the paste are different in the different processes, but various gums, sugar, syrup and other viscous liquids form the binding materials with which the metallic tungsten powder and some form of carbon are mixed. When the filaments come from the die they are dried and gently heated away from air. They are then ignited by an electric current in an atmosphere of hydrogen (or other reducing gas) and sufficient oxygen (or water vapor) to dispose of the carbon. They are hardened at very high temperatures.

The General Electric Company has patented a process in which the binding mass is an alloy of 42 parts cadmium, 5 to 10 parts of bismuth and 53 parts of mercury. With 35 parts of this alloy are mixed 65 parts of metallic tungsten and a refactory oxide such as that of thorium. The filaments are finished by electrically heating them in an atmosphere of hydrogen. In one process, metallic tungsten is mixed with an oxide of one of the metals: titanium, thorium, zirconium, or

vanadium, or with a mixture of the oxides of two or more of these. Filaments having a coating of tungsten over a core of another metal have been tried, as have also hollow filaments made by coating a carbon filament with tungsten in an atmosphere consisting of a halogen or an oxyhalogen of tungsten. The carbon core is removed by burning the filament in an atmosphere containing nitrogen and hydrogen. A partially metalized filament is made by packing carbon filaments in oxides of tungsten and heating them in a vacuum furnace. The oxides are partially vaporized, and entering the carbon, are reduced to metallic tungsten.

The brittleness of the tungsten filament is probably due to the presence of a carbide (or an oxide) of tungsten. In most of the methods of manufacture there would be little danger of an oxide remaining, but the carbides, W_2C and WC may be present in the metallic tungsten powder used, and under certain conditions the carbide W_2C may be formed in the making of the filament.

It is interesting to note that two or more of the large manufacturers of incandescent lamps specify that Boulder County tungsten must be used in the filaments. Most of the foreign tungsten deposits are associated with, or contain, minerals carrying one or more of the following elements: sulphur, phosphorus, tin, arsenic and antimony, all of which render the metallurgy more complex, and make the production of a pure metallic tungsten more difficult. Even a small trace of sulphur, phosphorus, tin or arsenic is said to be very detrimental to the filament, and it is very reasonable to suppose that sulphur and phosphorus are as objectionable in ferrotungsten and tungsten steel as they are in ordinary steel. Probably the only foreign tungsten deposits which compare in purity with the Boulder County ores are those of Saxony and Bohemia.

Some of the claims made for the tungsten filament are: brilliant white light; increasing resistance with increasing heat; an efficiency of 1 to 1.2 watts per (Hefner) candle power; (the ordinary carbon lamp uses from 3.5 to 4. watts per candle power); an average efficient life of 1,000 hours; that it is but little affected by irregularity of voltage. **(116.)**

Tungstic oxide, WO_3, has but few direct commercial uses. Certain metallurgical processes for the production of metallic tungsten, ferrotungsten, tungsten steel and other alloys, may be said to start with the tungstic oxide, while in others, such as

the fusion-lixiviation method, its separation from the sodium tungstate is one of the steps in the process. It is the essential part of certain mordants used in dyeing textile materials and fabrics. It is also used in paper staining and printing. But in both these uses a tungstate (usually the sodium paratungstate), is used as a source of the oxide, and it is probable that tungstic acid, H_2WO_4, rather than the oxide, is the form in which tungsten takes part in the reactions. Sodium- and barium-tungstates are used in glass-coloring and pottery glazing. The colors obtained include various shades of yellow and blue.

The tungstates are the chief ores of the metal, and are therefore the primary source of tungsten in whatever form it may be used in the industries. The insolubility (in water) limits the direct use of the natural tungstates except as sources of the metal and its commercial compounds. Scheelite is used in the Roentgen ray fluoroscope. Tungsten forms soluble tungstates with sodium and potassium. Those of sodium are by far the most important, and are made by fusing powdered wolframite, hubnerite or ferberite with sodium carbonate. Sodium paratungstate, the commercial sodium tungstate, $Na_{10}W_{12}O_{41}.28H_2O$, is the most important artificial tungstate. It is used as a mordant in dyeing and calico printing, and for rendering vegetable fibers and fabrics uninflammable. Sodium tungstate and other tungsten compounds characterized by rich color tones are used in the manufacture of stained papers. Tungsten salts are also used for weighting silk fabrics.

The partial decomposition of the sodium and potassium tungstates yields a series of tungsten bronzes of very beautiful colors and high lusters. A fusion of potassium tungstate and tin yields "bronze powder." These tungsten bronzes and bronze powder are much used for decorating. Lead tungstate was sometimes substituted for white lead as a pigment.

ALLOYS OF TUNGSTEN.

Various alloys: Tungsten forms useful alloys with many metals. It unites in almost any proportions with iron and steel. (The iron and steel alloys will be discussed more fully below.)

Platinoid contains copper, zinc, nickel and a small percentage of tungsten. Its high electrical resistance does not decrease with heat. "Wolfram-aluminum" is a very useful alloy, which may be rolled, spun and woven. It is used for military appliances. A light and very strong alloy of tungsten and aluminum,

called partinium, is used in automobile manufacture. An alloy of tungsten, aluminum and copper, having great tensile strength and elasticity, is used for propeller blades. Sideraphite contains much iron, with nickel, aluminum, copper and 4 per cent. of tungsten. It is malleable, ductile, and resists acids. Minargent is an alloy of tungsten, nickel and copper. An alloy containing 73-75% tungsten, 23-25% nickel, a small amount of iron, carbon and silicon finds a ready market. The so-called alloys with manganese are unstable, and are probably not true alloys, since the manganese can be dissolved out, leaving a tungsten web or network. There are several alloys with iron and nickel; with nickel alone, and with iron and chromium. Alloys of tungsten and titanium and tungsten and zirconium have been used with good success as filaments for incandescent lamps. Alloys of tungsten, with copper and iron; iron, copper and aluminum; iron, titanium and carbon; iron, columbium and tantalum, are available.

Carbides of tungsten and chromium are extremely hard, and resist acids well.

Iron and steel alloys: The alloys of tungsten with iron and steel are by far the most important. Those with iron are known as ferro-tungstens, and ferro-alloys. Their chief use is in the manufacture of tungsten steels. Those with steel are known as tungsten steel, wolfram steel, high-speed steel.

Ferro-tungsten: The ferro-tungstens commonly carry from 30 to 85 per cent. of tungsten. They are sometimes classed according to the percentages of carbon and tungsten into: *a*, high carbon and medium tungsten; *b*, high carbon and high tungsten; *c*, low carbon and high tungsten. Those having the higher percentages of tungsten are favored. The following are typical:

	W	Fe	C	
1	60.92	28.38	---	
2	83.90	12.10	3.30	
3	78.80	10.90	3.20	
4	84.30	14.90	.72	
5	85.79	13.50	.60	
6	85.15	14.12	.45	
7	71.80	24.35	2.58	Mn. 78

The temperature required for the making of ferro-tungsten cannot be reached in the blast furnace. There are several methods of manufacture in use: 1. The direct reduction of the tungsten concentrates (with scrap iron, or iron ore if necessary) in

a Moissan or other electric furnace; 2. The Rossi method, which combines the electric furnace and a modified aluminum process. A graphite-lined furnace is so arranged that the lining becomes the cathode, and a carbon electrode dipping into the furnace cavity forms the anode. Scrap or bar aluminum is charged into the furnace and the current turned on. The aluminum forms a molten bath in which the tungsten concentrates, consisting mainly of $FeWO_4$, (or $FeO.WO_3$), are placed. The iron oxide is reduced to a metallic bath in which the tungsten dissolves. The aluminum takes up the oxygen of the concentrates, forming a slag on the surface of the molten ferro-tungsten. This produces an alloy low in carbon. 3. The crushed ore or concentrate is mixed with the proper amount of iron, either metallic or in the form of an ore, and ten to fifteen per cent. of charcoal, a like amount of pulverized quartz, and five per cent. of scrap glass. With rich ores or concentrates, a small percentage of resin or pitch should be added. The mixture is placed in graphite or clay crucibles and fused in a crucible furnace, or a gas regenerative furnace.

Tungsten steel: The effect of tungsten as a steel-hardening metal was known as early as 1855, but it was not until Robert Mushet, an English iron master, placed his "special steels" on the market a few years later, that any commercial use was made of the knowledge. The Mushet steels contained tungsten in varying percentages from 6.4 up to 10. They were known as self-hardening, or air hardening, or high-speed steels. It was later discovered that tools made of the Mushet steel, reheated to a yellow heat, and cooled in a current of air, possessed greater hardness and greater cutting-efficiency. The Mushet steels contained less tungsten and more manganese than the average high-speed steel of to-day. The special qualities given to steel by the addition of tungsten depend upon a nice balancing between the carbon (manganese) and tungsten. Several contain chromium also. With 3% of tungsten and 0.9% carbon, the tenacity of the steel reaches its maximum, and its ductility is not materially decreased. As the percentage of tungsten rises from 9 to 16, the steel becomes very hard and brittle, but its efficiency in cutting tools is greatly increased. Beyond 16% of tungsten, the steel becomes softer and tougher and the cutting efficiency decreases.

Taylor and White, of Bethlehem, Pa., recommend the following steels:

	W	Cr	C
1. For cutting hard steel	8.5	4.0	1.25
2. For cutting soft steel	8.5	3.0	0.75 to 1.0

The analysis of one of their best high-speed steels, the "A. W.," shows: Tungsten, 13.5%; chromium, 3.5%; carbon, 0.55%.

H. M. Howe (Iron, Steel and Other Alloys) gives the following ranges for many of the tungsten steels:

W	3.44 to 24.00
Cr	0.00 to 6.00
C	0.40 to 2.19
Si	0.21 to 3.00
Total	4.05 to 35.19

Nickel is also added to some tungsten steels.

In an iron-working machine, when a cutter made of hard carbon steel develops a temperature, through friction, of about 500° F., it begins to lose its temper. This fact limits the speed at which the machine may be run. The tungsten steel cutters do not begin to soften until a temperature of 1,000° F. to 1,200° F. is passed. The tools are completely restored by reheating to a very high temperature and cooling in an air blast. They are, therefore, not strictly self-hardening. It is also found that the higher the temperature used in reheating, the higher may be the temperature developed by friction before the tool will soften.

The uses of tungsten steel: 1. The tougher grades are being used for armor plate, and the harder for heavy projectiles. Edge tools and various other kinds are being made of tungsten steel.

2. The harder grades are used for cutters for steel- and iron-working machinery.

3. Car springs of high carrying power are made of the more elastic grades. Tungsten steel has also been used with excellent results for railway frogs and rails in places where the wear is very heavy.

4. Tungsten steel will retain a high degree of magnetism for a long period, and is therefore used for "permanent magnets," such as compass needles, and calibrating instruments.

5. Sounding plates and wires for musical instruments, made of tungsten steel, give a more powerful response.

6. It is reported that heavy guns, car wheels and the wearing parts of heavy machinery are being made of tungsten steel.

7. An alloy containing 35% tungsten and 65% iron is used for shells for lead bullets to increase their penetrating power.

Manufacture of tungsten steel: Probably the earliest method of making tungsten steel was by adding tungstic oxide to the molten steel in the crucible. Later, Mushet mixed roasted wolframite with pitch and added it to the crucible. The product of these methods would be irregular in the percentage of tungsten, and would be likely to contain unreduced tungstic oxide in damaging amount. Then followed the methods described below, and now in use:

1. Powdered metallic tungsten is added to the steel in the crucible until the desired percentage of tungsten is reached.

2. Ferro-tungsten of known composition is added in proper amount. Several other processes have been patented, of which the following may be regarded as a type; tungsten concentrates (or ore), metallic zinc and iron are heated in an electric furnace. The zinc reduces the oxides of iron and tungsten, forming zinc oxide, which is carried away. (124a).

The first method is favored in Germany and is largely used in America. The second method is more used in England, ana the following reasons are advanced in its favor: The powdered metal oxidizes readily at red heat, and is likely to carry tungstic oxide into the steel; the ferro-tungsten unites more readily with the steel and with less loss; the powder is more likely to carry impurities than is the ferro-tungsten; the ferro-alloy costs less per unit of tungsten than does the powder. The lack of uniformity in the earlier tungsten steel is believed by Hadfield, of Sheffield, to be due to the fact that more or less oxide was introduced with metallic tungsten.

SUPPLEMENTAL REPORT

EXTENSION OF THE AREA.

At the time of writing the report now reprinted, tungsten ore had been found at numerous points beyond the border of the map accompanying the report, but none of these findings had been sufficiently developed to justify the extension of the mapping to include them. Under the stimulus of the present high prices these bordering areas are being thoroughly investigated, and abandoned prospects and low grade properties are being converted into profitable mines. The reports of promising finds in Gilpin county, and the pushing of the prospected territory westward and northwestward are very gratifying. As suggested on p. 85 there are no geological reasons why the tungsten ores should be confined to the area in which they are now mined. It is to be hoped that the coming of spring will witness very active, intelligent prospecting on all sides of the known tungsten area, and in other regions of similar geological formations and structures elsewhere in the state. The geological map of Colorado shows that formations and structures similar to those about Nederland are very widespread.

Much of this area has never been prospected for tungsten. The fact that it may have been gone over for other ores or other metals is no argument against thorough examination for tungsten ores. The known tungsten area is, in large part, an old mining region on the surface of which lay tungsten float, but no one was sufficiently interested in this "black iron" or "bastard silver ore" to have it tested to determine its real composition or possible value.

TUNGSTEN IN OTHER COUNTRIES.

The only important producer to enter the field since the first issue of the Report is India. The occurrence of tungsten in Tenasserim and other parts of Burma was mentioned, but the first reported production was 7 tons in 1909.

In 1911 India led the world with a production of 1329 metric tons, and she has maintained her position from that date. The principal output comes from Tenasserim and the Southern Shan States. In Tenasserim the Tavoy and Mergin districts are the chief producers. The mining areas are hard to reach and the climate is very trying. The ore is wolframite, or possibly ferberite, and occurs in both placer deposits and fissure veins.

The greater part of the production comes from the placers where the ore occurs in lumps ranging in size from that of a marble to masses of several pounds. The alluvium containing the ore is washed in running water. The wolframite is picked out by hand and freed from rock and earth by breaking and re-washing. On account of the scarcity of water mining operations are confined to about five months in the year.

The vein deposits occur in the mountains farther east. Metamorphic rocks derived from shales and clays overlie an intruded granite which is responsible for the metamorphism. The veins cut the metamorphic rocks and pass down into the granite. The metallic minerals of the veins include pyrite, arsenopyrite, cassiterite, and wolframite, (or possibly ferberite). The principal gangue is quartz. The veins have been grouped as:

1. Wolframite-quartz lodes;
2. Cassiterite-quartz lodes;
3. Wolframite greisen.

The South Shan States bid fair to rival or outstrip Tenasserim as producers of tungsten.

Portugal has maintained her place as the largest European producer of tungsten. New deposits have been opened in the Serra da Estrella mountains and elsewhere in the central and northern parts of the country. With the exception of a part of the ore from Castello Branca the Portugese tungsten ores carry tin, and most of them are associated with pyrite and arsenopyrite.

Canada has become a small producer of tungsten. Scheelite is mined in Nova Scotia.

Japan produces between 200 and 300 metric tons per year.

THE BOULDER COUNTY TUNGSTEN MINERALS.

Ferberite: During times of low prices ferberite finds a much more ready market than do the other ores of tungsten. This is due to the facts that the principal ore of the United States is the Boulder County ferberite, which is very nearly free from objectionable impurities, is more easily smelted than any of the other ores especially in electric furnaces, and can be used directly. Hubnerite, scheelite, and to some extent wolframite require different fluxes and the refiners prefer uniformity of practise. At the present time when ferberite is selling as high as $90.00 per unit of tungstic acid all the ores are in demand though some buyers refuse the highly manganiferous hubnerite.

Scheelite is being found in greater quantity than formerly in the Boulder area, but it cannot, as yet, be regarded as a factor in

the production. It is intimately associated with the country rock and in some instances clearly represents a partial replacement of it. It is not likely to increase in the deeper workings.

Some specimens of scheelite from near Boulder Falls appear to be replacements of a porphyritic dike rock. They retain the porphyritic texture, and except for their high specific gravity may be readily mistaken for weathered country rock. It is reported that considerable quantities have been thrown aside as "heavy country rock."

Hubnerite has been found in commercial quantity in only a small area between Black Tiger Gulch and Boulder Falls. At the junction of the Elmettie vein with an intersecting vein from the northwest a very large body of hubnerite was found. At other points along the Elmettie small amounts of this mineral occur. On the outer borders of the area in the direction of Ward, and in the Ward mines the tungsten mineral is almost all hubnerite.

Nothing that can be called wolframite is found in appreciable quantity in Boulder County.

Tungstic ochre, Tungstite: Within the last year several specimens of ferberite showing considerable coatings, and in one or two instances vug fillings, of tungstite have been found. The quantity of tungstite is far too small to give it any commercial significance. The mineral is a soft, earthy, yellow to yellowish green powder crumbling under the touch, occasionally showing traces of crystal faces when examined under a strong lens. Its composition is WO_3, with tungsten 79.3 per cent. It results from the alteration of ferberite.

The yellow powder formed in the ordinary tests for tungsten is of the same general composition, color and properties as tungstite, but is usually somewhat hydrous, and in this respect more nearly approaches meymacite in composition. An earthy, kaolin-rich vein matter from near Magnolia also shows the presence of tungstite, but in very limited amount.

THE DARK TUNGSTEN MINERALS.

It is a well recognized fact that there is no natural subdivision of the dark tungsten series into the three minerals hubnerite, wolframite and ferberite. They form a series graduating from almost pure manganese tungstate at the one end to an almost pure iron tungstate at the other. In the middle of the series are forms in which the manganese tungstate and the iron tungstate are present in almost equal amounts. Hess has proposed the following definitions for what he calls the wolframite series:

"*Ferberite:* A monoclinic iron tungstate having when pure the composition, $FeWO_4$. It may contain not more than 20 per cent of the hubnerite molecule, $MnWO_4$.

Hubnerite: A monoclinic manganese tungstate having when pure the composition $MnWO_4$. It may contain not more than 20 per cent of the ferberite molecule, $FeWO_4$.

Wolframite: A monoclinic mineral containing the ferberite molecule, ($FeWO_4$), and the hubnerite molecule, ($MnWO_4$), in all proportions between 20 per cent $FeWO_4$ and 80 per cent $MnWO_4$ and 80 per cent $FeWO_4$ and 20 per cent $MnWO_4$."

ASSOCIATED MINERALS.

The general and detailed mineralogy of the tungsten area is now better known than it was when the Report was first issued. Though probably only one new mineral has been discovered, other associations are better understood. The presence of *a secondary feldspar,* supposed to be adularia, had been observed in a number of veins in the Nederland and Beaver Creek areas. Hess finds that it is adularia. *Calcite* had been observed in the Conger, Beddig, Townlot and other mines of that vicinity, but it is not mentioned in describing the veins. *Fluorite* had not been definitely determined, but its presence was suspected, (p. 75). Within the last year two or three specimens of ore carrying considerable amounts of purple fluorite as a gangue mineral have been sent to the Survey office. *Free gold* has been found probably a dozen times during the last year in panning lean ores for tungsten tests.

Hamlinite (?): Almost from the first real mining of tungsten in Boulder County the presence of traces of phosphorus had been noted in the complete analyses of the ores. The writer thought it might come from apatite in the country rock gangue, since apatite is commonly present in granite. But the work of Hess and Schaller has shown that there is present in some of the ores, a very light green mineral having a specific gravity between 2.8 and 3.0, and a perfect basal cleavage. It appears to be related to hamlinite but not identical with it. On account of its low specific gravity a large part of it should disappear in concentration, and as a consequence the concentrates should carry a lower ratio of phosphorus than the raw ore.

CONCENTRATION.

In the matter of concentration, the principal changes that have been adopted since the writing of the report are intended to avoid excessive sliming and to effect a readier saving of the ore. They consist mainly in the decreased use of stamps, an increased use

of rolls, the introduction of jigs, and more frequent sizing and classification.

Experiments in the dry concentration of the ores have given some very satisfactory results, and it is reported that at least one of the proposed new mills will be equipped with these machines.

Flotation has not, so far, proved a success in the concentration of tungsten ores.

METALLURGY.

Perhaps the most important advance in the metallurgy of tungsten is the preparation of pure, ductile, metallic tungsten. Other investigations have resulted in the modification and improvement of processes already in use. Some of these have to do with the preparation of low phosphorus metallic tungsten and ferro-tungsten from phosphorus bearing ores. Others aim at the elimination of carbon from metallic tungsten and the ferro alloys. Still others have been directed to the more satisfactory handling of high-manganese tungsten ores such as hubnerite. The recovery of metallic tungsten from steel scrap is another line of investigation.

By the Becket process, low-phosphorus ores, ground to 100-mesh, are mixed with sulphuric acid which dissolves out a large proportion of the phosphorus without important loss of tungsten. High-phosphorus ores are roasted before treatment with the acid. After the acid treatment the ores are washed, dried and smelted in the usual way.

The Goldschmidt process has been modified and adapted to the direct treatment of ores and concentrates.

Ductile tungsten is prepared somewhat as follows: The tungsten trioxide, WO_3, is purified by reducing it to the dioxide, WO_2, volatilizing this to the oxychloride and treating the product with hydrochloric acid. In volatilizing the dioxide, silica and phosphoric acid are left behind as a residue. In the acid treatment tungsten trioxide is precipitated and arsenic and antimony are held in solution. The trioxide is reduced in a current of hydrogen at a temperature of 1250° C., and a fairly coarse, pure metallic powder is obtained. The powder is formed into rods by subjecting it to enormous pressure. The rods are hardened by heating in an atmosphere of hydrogen to 1300° C., and then sintered into a connected mass in a special furnace at a temperature of about 2650° C. The metal is still brittle, but is rendered ductile by repeated heating and swaging. The ductility of pure tungsten, so produced, is very high. (See Min. Ind. 1912, pp. 84-89.)

USES OF TUNGSTEN.

The manufacture of tungsten steel consumes by far the largest part of the tungsten produced. Simple tungsten steel is an ordinary carbon steel to which tungsten has been added in percentages varying with the use to which it is to be put. One of the principal uses of simple tungsten steel is in the manufacture of permanent magnets such as are used in electric meters, the magnetos of telephones, automobile ignition systems, separately excited dynamos, and in certain scientific apparatus. It is also used as a tool steel for finishing purposes where a comparatively light cut is required and where high speed is not important. It is not self tempering, but must be hardened by quenching in water and drawing. A comparatively new use is for automobile valve stems. It is estimated that the manufacture of permanent magnets requires about 6000 tons of simple tungsten steel annually.

Most high-speed steels contain two or more alloying metals. Those containing two alloying metals are known as quaternary steels, while those containing three or more alloying metals are called complex steels. The principal alloying metals used in high-speed steels are tungsten and chromium, but vanadium, cobalt and manganese are sometimes used. Tungsten is used in both quaternary and complex steels. The tungsten content generally ranges between 16 and 20 per cent and the chromium from a little below 3 to a little above 5 per cent.

The use of high-speed steels effects great savings in time, power and overhead charges in the working of metals. These steels excel the old carbon tool steels in the thickness of the chip or cut, in the rate of cutting and in length of service without dressing. They are also used on steels which are too hard for the carbon steel tool.

The specification of the U. S. government for high speed tool steel to be used in the navy yards may be taken as representing very fairly the present requirements. These are as follows: carbon, 0.55 to 0.75 per cent.; chromium, 2.5 to 5.0; manganese, 0.05 to 0.03; phosphorus, 0.15; silicon, 0.3; sulphur, 0.02; tungsten, 16.00 to 20.00; vanadium, 0.35 to 1.50; iron, 72 to 80.5 per cent.

TUNGSTEN STEEL.

For several years prior to 1915 the American production of tungsten tool-steel ranged from 6000 to 7000 tons. The 1915 output far exceeded this figure, and that of 1916 will be, in all probability, double the average of preceding years. A few years ago there was but little tendency toward uniformity in the composition

of high-speed steels, but experience has shown rather clearly the most satisfactory limits for the various alloying metals with iron.

There is much difference of opinion as to whether tungsten steel is used in the make-up of heavy guns, mortars and howitzers. Men who should be in a position to know assert positively that it is not so used, while others equally close to the sources of information are quite as confident that it is so used. Hibbard states that the Austrian government uses tungsten steel for the tubes of cannon. It is commonly reported that the French have used tungsten steel even more extensively in artillery, and that the British arsenals are using it in the bodies of field guns. Fink, who is unusually well posted in the technology of tungsten, says in a private communication dated March 16, 1916: "Tungsten steel enters into the composition of our large guns and also smaller ammunition." It is used in the machining of shrapnel, but not in the composition.

As to its use in armor plate there is equal difference of opinion. One buyer who has acted as agent for the U. S. government on different occasions states positively that the U. S. Navy specifications for armor plate and those of certain other governments include a certain percentage of tungsten. It is objected that tungsten makes steel harder, but more brittle, and, therefore, less suited to the manufacture of armor plate. This is true up to a certain percentage of tungsten, but Gledhill has shown that steel with 18 to 27 per cent of tungsten is tough and not brittle. In the first issue of this Report attention was called to the varying effects of tungsten on steels. The use of high-speed steel has brought out similar facts in relation to the speed of highest efficiency in cutting.

Wrought tungsten, on account of its high specific gravity, is being tested as a metal for rifle bullets and other small projectiles. It is highly probable that the equipment of factories with high-speed tool steel, for manufacturing munitions of war is responsible for a very large part of the extraordinary demand for the metal.

METALLIC TUNGSTEN.

Ductile, metallic tungsten has become a market commodity within the last three or four years. This has greatly extended the minor uses of tungsten, and researches now under way promise many interesting discoveries and new uses for this magic metal. Its physical and chemical properties are of such an extraordinary

character that it is safe to predict a remarkably wide field of usefulness in the arts and sciences.

A few of the possibilities of ductile tungsten are here listed from a paper by Dr. C. G. Fink of the General Electric Company's research staff.

1. A substitute for platinum and platinum alloys as contact points in spark coils, voltage regulators, telegraph relays, resisters in electrical laboratory furnaces, and as targets in Roentgen tubes.

2. In the form of gauze it could be used for the separation of solids from acid liquors, as, for example the removal of sludge from copper refining baths; the manufacture of acid proof dishes and tubes.

3. In calibrating instruments and apparatus, such as standard weights, standard resistances, electrical meters, and many others.

4. Its chemical stability and resistance to change under atmospheric conditions make it suitable for many uses where delicate, yet strong metallic wires, points and springs are needed, as in watch springs, pen points, drawing dies, cross hairs in telescopes and other optical instruments, galvanometer suspensions and the wires of musical instruments.

The ductile metal is now drawn through dies into wire of any desired size down to a diameter of 0.0002 inch, (one-sixth the diameter of a fine human hair). (The dies for the finest wire consist of drilled diamonds.) As a consequence, the metallic tungsten wire filament for incandescent lamps has completely replaced the "paste" filaments described in the first issue of this Report, and the carbon filament is doomed. In 1913 the gas-filled incandescent tungsten lamp was placed on the market. This consists of a metallic, tungsten filament in a globe filled with nitrogen. This change reduces the consumption of current to about one-half watt per candle power, as compared with 1.25 watts per candle power for the vacuum lamp. The life of the filament is also prolonged because of the reduced rate of evaporation of the metallic tungsten in an atmosphere of nitrogen.

The light produced by the gas-filled lamp approaches day-light in whiteness.

It is estimated that the total American consumption of metallic tungsten for lamp filaments does not exceed two tons per year.

THE PHYSICAL AND CHEMICAL PROPERTIES OF THE METAL.

Specific gravity, 19.3 to 20.2.

Tensile strength in pounds per sq. inch, 610,000.

(Tensile strength of extra steel, 450,000).

Modulus of elasticity in pounds per square inch 60,000,000. (Steel 30,000,000).

Melting point, 3267° C., (This is much higher than that of any other metal, and probably higher than that of any known substances except carbon, and perhaps, boron. Platinum melts at 1710° C.).

Hardness, variable, ranging from 4.5 to 8, depending upon treatment. The hardest will easily scratch glass.

Coefficient of expansion at 18° C. is 0.0000035 while that of platinum is 0.0000088.

It is practically non-magnetic.

It is insoluble in hydrochloric, nitric, sulphuric and hydrofluoric acids, sodium and potassium hydroxides and mixtures of potassium chromate and sulphuric acid. It is soluble in mixtures of hydrofluoric and nitric acids and in fused nitrates and peroxides.

ALLOYS.

Many new alloys have been patented, and some of these have been placed on the market for various purposes. An alloy containing 20 to 60 per cent tungsten and 80 to 40 per cent platinum is recommended for electrical contacts and for jewelry. Alloys of tungsten and thorium have been patented. The tensile strength of aluminum is increased by the addition of about 1 per cent of tungsten. Duralium is an alloy of tungsten and aluminum containing 2 to 3 per cent of tungsten. A new type metal contains: tungsten 10 parts, copper 10 parts and aluminum 80 parts.

Stellite, an alloy of cobalt and chromium, invented by Haynes, has been modified and greatly improved for certain purposes by the addition of tungsten. When the chromium is held at 15 per cent and tungsten added in amounts varying from 5 per cent to 40 per cent, the hardness and cutting qualities of tools formed from it are greatly increased. Tests indicate that it far surpasses the high-speed steels. (Alloys of Cobalt with Chromium and Other Metals by Elwood Haynes, Bull. A. I. M. E., Feb. 1913, pp. 249-255.

TUNGSTEN PRODUCTION ON BASIS OF 60% WO_3.

	Weight Tons	Range per unit	Value
1907	1,146	$5.00-$9.00	$573,643
1908	587	Very Poor Market	164,220
1909	993	$5.00-$9.00	391,160
1910	1,221	$6.50-$8.50	553,100
1911	730	$4.50-$8.50	261,492
1912	775	$5.60-$7.50	293,611
1913	953	Rather Steady at about $7.50	428,726
1914	630	$5.85-$9.00	252,000
1915	---	$5.50-$45.00	------

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ABBREVIATIONS.

A. I. M. E.—Transactions of the American Institute of Mining Engineers.

Am. Chem. Jou.—American Chemical Journal.

Am. Jou. Sci.—American Journal of Science.

Ec. Geol.—Economic Geology.

E. M. J.—Engineering and Mining Journal.

Eng. Mag.—Engineering Magazine.

J. A. C. S.—Journal of American Chemical Society.

Jou. I. and S. I.—Journal of the Iron and Steel Institute.

J. S. C. I.—Journal of the Society of Chemical Industry.

Min. and Geol. Mus.—Mineral and Geological Museum.

Min. Ind.—Mineral Industry.

Min. Jou.—Mining Journal.

M. R.—Mineral Resources.

Min. Rep.—Mining Reporter.

Min. Sci. Press—Mining and Scientific Press.

Quar. Jou. Geol. Soc.—Quarterly Journal of Geological Society.

Soc. of Engs. and Mets.—Society of Engineers and Metallurgists.

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TOPOGRAPHY BY U. S. GEOLOGICAL SURVEY
CULTURE MODIFIED BY
COLORADO GEOLOGICAL SURVEY

TOPOGRAPHIC MAP OF THE MAIN TUNGSTEN AREA

BOULDER COUNTY, COLORADO

⚒ MINE
× PROSPECT

553.4647 09788
G293m

Section lines from U.S.G.S. shown
" " " " late U.S. Gov't surveys
(As worked out by Henry Drumm)

GEOLOGIC MAP OF THE MAIN TUNGSTEN AREA
BOULDER COUNTY, COLORADO.

Geology by R. D. George and R. D. Crawford
Surveyed in 1907-8

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